NORTHWESTERN ONTARIO FOREST TECHNOLOGY DEVELOPMENT UNIT

ASPECTS OF SITE PREPARATION

BIOLOGY AND PRACTICE

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FORWARD

These proceedings are a record of the indoor presentations session of a two day Site Preparation Workshop held in Fort Frances, Ontario in September of 1988. The second day consisted of an eight stop itinerary, designed to example some of the principles that were discussed during the presentations session.

Participants at the workshop were from both the Ontario and Minnesota forest industry and the Canadian, Ontario, British Columbia and Minnesota government forestry agencies.

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A follow-up presentation of this workshop has been presented at Red Lake and is available as a part of the Mini-workshop series of the Northwestern Ontario Forest Technology Development Unit upon request.

As a result of the stimulus of this workshop there have been some further studies undertaken at the TDU:

- Forest Ecological Interpretations for Site Preparation, a joint project with Forestry Canada, contact Bill Towill, TDU, Thunder Bay or Brad Sutherland, Forestry Canada, Sault Ste. Marie.

- Final Development of the Gaspardo Seeder for Disc Trenchers, contact Pat Corbett, TDU, Kenora.

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Site Preparation Program In Ontario

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Synopsis

The site preparation program in the province of Ontario is heavily oriented towards mechanical methods. Currently, of the total work, about 78% is done by mechanical means (Figure 1).

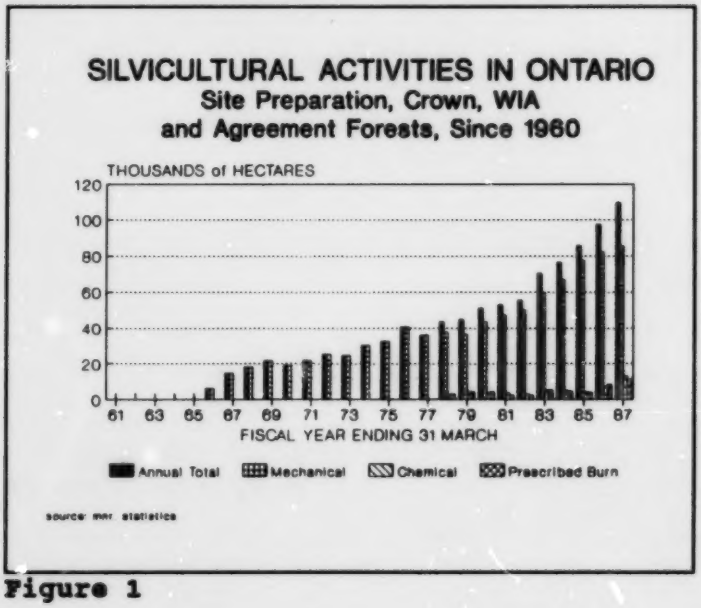

Figure 1

In Northwestern Ontario, the site preparation program is almost totally mechanical, 87% of the total in 1988 (Figure 2). This is partly due to the difficulty of conducting alternate methods, like prescribed burning, in this perennially, drier part of the province.

It is well recognized that the cost of mechanical site preparation is high. An approximate comparison of costs for the Northwestern Region is shown in Table 1.

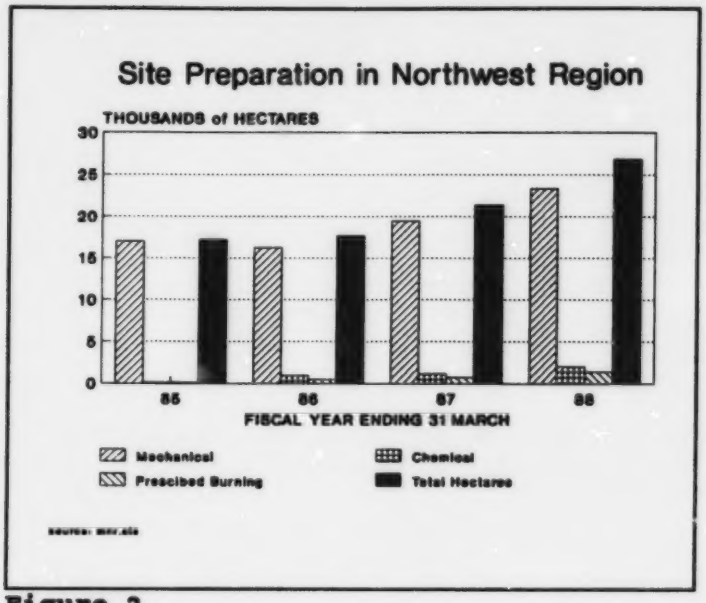

Figure 2

Although these figures are not exact, they are reasonable approximations. It is recognized that there is a certain amount of area that will be seeded which is generally less expensive. However, one does get the idea that regeneration is an expensive business.

Table 1: Comparison of costs of regeneration components for Northwestern Ontario

Site Preparation

Mechanical	23,364 ha.	x $220 =	$5,140,000
Chemical	2,045 ha.	x $ 90 =	$ 184,000
Burning	1,395 ha.	x $139 =	$ 139,000
Total SIP	26,364 ha.		$5,463,000

Regeneration tree cost $400/ha., shipping cost $20/ha., planting cost $300/ha.

Therefore the approximate cost to regenerate one hectare is $720/ha. x 26,804 ha. = $19,300,000.

The implications are that the site preparation of only one hectare at $220 involves the intention to spend another (up to) $720 per hectare. The aggregate total is close to $1000 per hectare.

From this analysis we can see that each hectare of site preparation involves a spending escalation factor of 3.3. That is, each dollar spent on site preparation commits another $3.30 to be spent in the future in order to complete the regeneration process. The importance of doing the site preparation job properly in the first place is obvious from the financial aspect alone.

It is hoped that the proceedings of this workshop will give the participants an improved insight into the site preparation process, and its impacts on tree survival and growth; particularly from the aspects of temperature and nutrition, areas not well covered in the past.

Practice and Biology of Mechanical Site Preparation: Why Bother ?

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Abstract

The importance of the biological aspects of mechanical site preparation is discussed. Documented examples of early seedling survival and growth demonstrate the potential for obtaining variable results from different site preparation treatments within and among sites and for different species and stock types. Some implications of achieving, by design or accident, poorer or better results from mechanical site preparation treatments are indicated with respect to final yield, site preparation costs, and overall financial returns as expressed by net present value (NPV). Further research and long-term growth results are needed to strengthen the biological knowledge base, so as to improve site preparation practice and permit meaningful analysis of the implications of different site preparation practices.

Introduction

It is interesting to note that the terms "practice" and "biology" appear together in the title of this workshop. In the past, at similar meetings in Ontario, the enphasis has been on the operational rather than the biological aspects of mechanical site preparation. For example, at the first major meeting on this topic in the province, the 1975 COJFRC Symposium entitled "Mechanization of Silviculture in Northern Ontario" (Anon. 1975), biology, though included on the agenda, was not a prominent part of it. Similarly, the title and program of the CFS/CPPA seminar in 1984, "Mechanization of Silviculture: Increasing Quality and Productivity" (Anon. 1984), reflect a primary interest in the mechanical aspects of silviculture.

By examining the purpose and potential benefits of practising biologically sound mechanical site preparation, we hope, in this paper, to demonstrate that the term "biology" does indeed deserve the top billing it has finally achieved in this workshop.

Purpose of Mechanical Site Preparation

Site preparation should give effect to a treatment prescribed for a given purpose. As noted by Sutton (1989), prescribed treatments should be directed toward the alleviation of constraints imposed on the stock chosen for regeneration. To meet the performance objectives of management, the prescriber must identify the constraints that normally can be expected to jeopardize the attainment of the objectives for a given site, and devise treatments to alleviate those constraints.

Common constraints listed by Sutton (1989) include the atmospheric factors of wind, air temperature, radiation, humidity and precipitation; the edaphic factors of soil depth, temperature, moisture, texture, structure, bulk density and fertility; and the biotic factors of harvesting residue, competition and pest fauna.

The manipulation of five physical site factors during harvesting and site preparation can influence most of these constraints, singly or in combination, to various degrees. These factors are residual vegetation, slash, duff (LFH), mineral soil, and site hydrology.

Residual vegetation may be manipulated mechanically by removing, reducing, crushing, comminuting, burying or incorporating vegetation into the soil. Inasmuch as "vegetation" comprises a living, dynamic complex of species, the treatments can change its vigour and species composition and, hence, its competitive potential. Slash can be removed, reduced, crushed, comminuted, rearranged or incorporated. Mineral soil can be exposed, displaced (overturned, ridged, piled, etc.), compacted, loosened, or

mixed. The water table can be adjusted; material can be drained from or into an area.

The manipulation of these physical factors is often considered to be the essence of mechanical site preparation. However, the success of ameliorative treatments depends on the extent to which they are identified and understood, the selection of appropriate physical site factors, the availability of necessary technology, and the extent to which practical considerations are allowed to compromise the optimal solution.

The last-mentioned factor and the realities of management dispel the notion that to achieve success we should strive for perfect site preparation treatments. Rather, we should ask: to what extent can performance be improved through better selection and application of site preparation treatments? How much effort and expense are warranted in achieving this end?

Improving Performance

Researchers often measure performance through early survival as it affects stocking, density and growth. Because mechanical site preparation is relatively new in Ontario, it is impossible to assess its long-term effects. Although much valuable experience was gained from early efforts at mechanical site preparation, detailed information on performance with respect to the range of possible manipulations of site factors is scarce. Even less work has been done on the biological basis of site preparation, which would have permitted the identification of short and long-term constraints. Our present information is preliminary, and much of it is from studies originating outside the province or country.

Potential Stocking: Microsite Creation

Aside from the limitations set by the accuracy of the prescription, potential yields are first affected and maximum limits are established by the number and distribution of desired micro-

sites that result from site preparation. Considerable work has been done in Canada on assessing microsite preparation quality (as measured against a predetermined prescription), and hence potential stocking for a wide range of site preparation implements. For example, from a series of trials on upland sites in northeastern Ontario, the Leno Patch Scarifier achieved a potential stocking of 63%, the TTS Mechanical Disc Trencher 82%, and the 2-row Bräcke Cultivator 93%, on similar full tree logged sites (Smith et al. 1985); the Donaren Powered Disc Trencher achieved a stocking of 83 to 90% over a range of full tree logged sites (Puttock and Smith 1986); on a range of sites containing residual poplars, Young's Teeth achieved within corridor stockings of 79 to 98%, but on a total area basis (including windrows), achieved stockings of 61 to 73% (Puttock and Smith 1987). Hence, results can vary among machines and, with the same machinery, within and among sites.

Survival

Survival of seedlings on available microsites is the next factor that affects potential yield. Although survival is also a measure of many unexpected factors outside the site preparation operation itself, there is overwhelming evidence that the type of microsite can have a major impact on survival. This is clearly illustrated by Hunt (1987) in a review of studies in Fennoscandia, North America and, to some extent, Britain, Germany and the Soviet Union. To illustrate the extent of the effect on survival, the following results identified from studies by Hunt and others are provided.

Where competition was a clearly identifiable constraint, McMinn (1985) reported that 10-year survival of white spruce (Picea glauca [Moench] Voss) container stock on a sandy spruce site in British Columbia with dense competition was 40% with no site preparation, but 89% with blade screefing. Ball and Kolabinski (1981) reported that, on upland sites in Saskatchewan

with hazel (Corylus sp.) shrub competition, fifth year survival of white spruce container stock was 78% with no treatment and 86% with blade scalping. On lowlands with alder (Alnus sp.) shrub cover, survival with no treatment was 85% and with scalping 94%.

With respect to alleviating constraints imposed by pests, Berg et al. (1981) showed increasing third year survival of bareroot Scots pine (Pinus sylvestris L.) in areas in Sweden (Kosta) infested with pine weevil (Hylobius abietis) with increasing distance from the seedling to undisturbed humus and increasing area of exposed mineral soil; i.e., 2% survival on untreated microsites, 21-33% on patches, 32-35% on disc-trenched furrows and 59% on small ridges.

In an extensive microsite comparison trial in Sweden, some experimental areas were sprayed with insecticide to reduce the effect of the pine weevil and to permit the observation of other constraints such as soil temperature and moisture (Söderström et al. 1978). On spring-planted, normally moist sites sprayed with DDT, 4-year survival of Scots pine bareroot stock was 38% (site 1) and 69% (site 2) on untreated microsites; 70 and 80% on heaps (15-20 L) on unscarified ground; 53 and 82% on patch-scarified spots; and 88 and 77% on heaps on patch-scarified spots. Similarly, survival of container stock was 12 and 72%, 48 and 94%, 28 and 83%, and 55 and 93%, respectively. For the overall trial, including Norway spruce (Picea abies [L.] Karst.) experiments and several other microsite comparisons, planting in heaps on patches or furrows gave, by far, the best survival rate compared with planting directly in scarified patches and furrows. Planting without scarification gave the poorest results, except on the moister soil. Soil temperature was higher and soil moisture was lower on the heaps, but not to such an extent that the soil was on the point of drying up, except where it lay in heaps on unscarified ground.

In Finland, Raulo and Rikala (1981) reported fifth year survival values for Scots pine bareroot stock of approximately

52% with no treatment, 57% on a disc trenched furrow, 64% on a Sinkkila scalp, 72% on the shoulder prepared by a reforestation plough, and 76% on hummocks created by excavator-type buckets. Similarly, Norway spruce survival was 73, 75, 82, 88 and 97%, respectively. Soil temperature was highest in the hummocks and on the shoulder.

Sutton (1984) reported variable 1-year survival of jack pine (Pinus banksiana Lamb.) bareroot stock on Brăcke patch, and hand made mound (20 L) microsites, on a range of jack pine sites in northern Ontario. With no treatment, survival was 81 to 100%, at the patch/mound hinge point it was 94 to 100%, at the bottom of the patch it was 95 to 100%, on mounds on mineral soil it was 86 to 100%, and on mounds on inverted LFH over undisturbed LFH it was 50 to 100%. Jack pine planted on mounds of predominantly sandy material experienced periods of sustained water stress.

These examples clearly show that survival of planted stock can vary greatly among different microsites on the same site, and among similar microsites on different sites; and that different species and stock types are affected differently by the same microsites.

It is beyond the scope of this paper to examine seeding in much detail. Briefly, however, a number of studies in Ontario have demonstrated the importance of adequate site preparation for several seeding applications. For example, Riley (1980) showed that for aerial seeding of jack pine in the Ontario Ministry of Natural Resources' Northern Administrative Region, stocking is directly related to the amount of receptive seedbed available. Stocking at acceptable levels requires that adequate seedbed be available regardless of seeding rate, and that seedbed must be well distributed through the area. In general, as the amount of receptive seedbed falls below 20-25% of the area, the stocking probability declines rapidly. Density increases rapidly with increasing seedbed availability. For natural seeding of black spruce (Picea mariana [Mill.] B.S.P.) in first cut, alternate

strip cuts in the North Central Region of Ontario, Jeglum (1987) stated that proper site preparation is the key to successful regeneration on upland sites. Optimum distribution of receptive seedbed, enough to achieve desirable levels of stocking without an overabundance of seedlings, is essential.

Long-term survival can also be affected by site preparation treatments. Windfall, in particular, can be a very serious factor. For example, as noted by Becquey (1986a), 10 to 20% of the annual commercial volume from softwood plantations in France is furnished by windfall, and this amount is increased dramatically by occasional, exceptionally severe wind storms that can destroy entire plantations. Becquey (1986b) stated that planting on berms created by large mouldboard ploughs can cause entire rows of trees to fall, particularly when water remains in the furrows and when the wind is perpendicular to the rows. Trees planted on mounds are less susceptible, although windfall does occur when mounds are close to water-filled ditches.

Growth

Although survival has a more immediate and predictable impact on future yield, the effects of growth are much harder to assess because of the time required to measure them and the possible conflict between the requirements of establishment and long-term growth.

Clear differences in early growth as a result of different site preparation treatments are reported in the previously mentioned studies, as well as in numerous others (see Hunt 1987). Differences stem from the effects of various methods of alleviating constraints. For example, the practice of mounding as summarized by Sutton (1984) has the potential for improving sites in various ways: by reducing competition; raising root zone temperatures during the growing season (because of the absence of an insulating mat of organic matter); improving drainage (in cases in which the water table is high); conserving what otherwise

would be runoff water (in the pits that provided the material for making the mounds); and providing the tree root systems close to an augmented source of nutrients, where the most biologically active part of the overturned organic layer contacts the relatively warm capping of mineral soil.

McMinn (1985) was optimistic about the long-term persistence of positive early results of mechanical site preparation treatments. He stated that, although the roots of planted trees soon outgrow the areas that can be modified by mechanical site treatment, and although the physical and chemical changes brought about by treatment disappear with time, positive and negative effects on tree growth may be evident well beyond the initial establishment period. He noted that white spruce bareroot stock growing on moist, fertile sites in British Columbia was approximately 0.8 m taller at age 13 when planted in tilled soil, than the same stock planted in blade-screefed soil. The continued divergence of the growth curves suggests that early improvements are persisting. Similarly, at age 10, white spruce container stock on fine textured soil had stem volumes of 350 cm^3 on screefed microsites, and 900 cm^3 on patches of inverted LFH. These differences continued to spread as the age of the stock increased. If the rotation age was reduced by appropriate site treatment, the allowable cut could be increased.

Nevertheless, some of the few long-term studies on which information is available indicate, as suggested by Hunt (1987), that initial benefits, at least in height growth, are not maintained. For example, Wilson and Pyatt (1984) reported 30-year results of both planting Scots pine and mixtures of Japanese larch (Larix leptolepsis [Sieb. & Zucc.] Gord.) and lodgepole pine (Pinus contorta Dougl.) on an upland heath in Britain after various ploughing treatments. In the first decade, height growth was rapid following all treatments, but deep ploughing elicited the greatest response. In the next decade, growth slowed and the order of response from the treatments was temporarily reversed.

By 30 years, height differences were small. However, the difference between the best and the worst results of the various treatments was about 20% in terms of volume production, which may be a better indicator of growth. Lundmark (1977) presented 40-year data comparing the results achieved with spade inversion, burning, clipping, and nontreatment on poor, dry sites in northern Sweden. At 40 years, initial differences in height were no longer apparent.

Wilson and Pyatt (1984) stated that it is unwise to draw conclusions about yield in cultivation experiments without at least 20 years of growth data. Wood and Dominy (1988) also stressed the importance of long-term measurements in assessing the suitability of treatments that, for example, may promote early survival by removing competition while actually reducing long-term growth. Fryk (1986) noted that influences on soil temperature and soil moisture are very important during the establishment phase. However, with respect to long-term growth, the proper choice of site preparation method can increase the site index, whereas a wrong choice may have the opposite effect; the two most important factors in the choice are hydrology and the availability of nutrients.

IMPACT OF IMPROVED PERFORMANCE

Forest managers measure performance according to final yield and various financial factors.

Final Yield

The previous examples of research results demonstrate that the selection and application of site preparation treatments may have an important effect on short-term survival and stocking. The implications of variable results in survival and stocking for final yield can be illustrated by the example in Table 1. On the basis of the range of results in the previous examples, an error in machine selection, may lead to the insufficient production of

desirable microsites, or the mismatching of microsite to site, and/or the planting crew's erroneous or inconsistent selection of optimal planting sites could reduce the stocking of jack pine, at age 10 in a site class I area, from 65 to 40%. If variable density yield functions (Evert 1976) are taken into consideration, such an error could reduce merchantable volume at age 60 by 18%. On the other hand, increasing stocking from 65 to 90%, perhaps by selecting the most appropriate machine and microsite type for the site and by ensuring correct planting spot selection, could increase volume by 8%. The effects are less pronounced in a site class II area.

Although selection and application of site preparation treatments may have significant effects on early growth, it is clear that the ability to assess the impact on final yield is limited by the lack of long-term data.

Financial Factors

The following examples of financial evaluations of various silvicultural treatment options help to determine how much effort and expense are warranted in attempting to meet or improve upon performance objectives. For this purpose, Net Present Value (NPV) has been selected as the financial criterion by which to compare and evaluate the relative monetary benefit of alternative treatment options. Expressed in terms of current dollars per hectare, NPV represents the sum of discounted flows of revenues and expenditures from the time of plantation establishment to harvest at rotation age. Although the calculation of the NPV estimate is precise and the calculated result is intuitively acceptable, NPV must be used with qualified caution. The NPV calculation presumes certainty within an uncertain or unknown environment; a sometimes tenuous presumption. Nevertheless, NPV is useful when the evaluation of alternative management options is predicated on a desire to maximize a given measure of monetary worth over time. Therefore, within a system of discounted value flows and a myriad of interrelated assumptions, changes in NPV may provide a useful

Table 1. Effect of varying stocking (2 x 2 m basis) and density at age 10 on merchantable volume of jack pine at age 60. After Evert (1976).

Site class (Jack Pine)	Stocking at age 10 (%)	Density at age 10 (no./ha)	Merch. vol. at age 60 (m^3/ha)	Change in vol. in relation to 65% stocking (%)
II	40	1000	131	-15
	65	1625	155	0
	90	2250	161	+4
I	40	1000	196	-18
	65	1625	238	0
	90	2250	256	+8

of impact if, for example, a single element of a system (e.g., site preparation expenditures) is varied and all other elements are kept constant. It is within this context that the NPV estimates in the examples provided may be used to compare the cost of site preparation options.

Current site preparation costs from the OMNR's Northwestern Region are used (Appendix A).

Example 1: Effect of early stocking on NPV rating.

In a jack pine site class I area, the management strategy calls for mechanical site preparation, bareroot planting in year one, and aerial herbicide treatment in year three. On the basis of merchantable volumes taken from Table 1, Table 2 indicates the effect that various stocking levels at age 10 have on the NPV rating at age 60. If 65% stocking is achieved, then significant relative losses in the NPV rating may be incurred if early stocking falls below 65%; conversely, significant gains may be possible for increases in early stocking above 65%.

Example 2: Effect of increased early stocking on NPV rating and site preparation costs.

In both site class I and II jack pine areas, the management strategy calls for mechanical site preparation followed by aerial seeding in year one, and spacing in year nine. If we assume that site preparation costs are $150/ha, how much more can be spent on site preparation if stocking can be improved from 65 to 75% at age 10? Table 3 (which uses the same data used in Table 1) indicates the effects that increased stocking might have on both merchantable volume at age 60, and the NPV rating. The higher potential gain in volume for site class I offers the most incentive for obtaining better stocking results.

Table 2. Effect of early stocking on NPV rating of site class I jack pine.

Stocking at age 10 (%)	NPV ($/ha)	Change in NPV[a] (%)
40	- 135	- 280
65	75	0
90	165	+ 120

[a]in relation to the NPV for 65% stocking at age 10.

Site preparation costs could increase from $150 to $165/ha for site class II and to $200/ha for site class I, with at least the same NPV rating.

Example 3: Effect of site-specific final yield increases on NPV rating and site preparation costs.

On a black spruce lowland containing both site class I and the higher site class Ia [1] areas, the management strategy calls for mechanical site preparation followed by container stock, hand planting in year one and aerial herbicide application in year three. It is assumed that site preparation will cost $400/ha and that the same treatment will be used for both site indices.

Table 3. Effect on scarification costs of increasing early stocking on different site classes.

Site class (Jack pine)	Stocking at age 10 (%)	Merch. vol. at age 60 (m^3/ha)	NPV ($/ha)	Site prep. costs at constant[a] NPV ($/ha)	Change in site prep. costs[b] (%)
II	65	155	240	150	0
	75	158	255	165	+10
I	65	238	655	150	0
	75	248	705	200	+33

[a] Site Class II, constant NPV = $240/ha
Site Class I, constant NPV = $655/ha
[b] in relation to the NPV for 65% stocking at age 10.

By applying more site specific techniques, i.e., by using a different treatment for each site class, can we justify higher site preparation costs if higher volume at rotation is the result? The NPV rating is calculated on the basis of black spruce variable density yield tables for managed stands in Northwestern Ontario[1]. If we assume a 10% (purely speculative) increase in final volume for each site class, site preparation costs could increase by $66/ha and $95/ha for site classes I and Ia, respectively, without a decrease in the NPV rating. As in example 2, the higher potential yield for site class Ia offers a greater

[1] Willcocks, A.J., Bell, F.W. and Williams, J. 1988. Establishing spacing regimens and rotation for conifer species - a northern Ontario case study. Ont. Min. Nat. Resour., Northwestern Ont. For. Tech. Dev. Unit. (in preparation)

incentive for applying an alternative site preparation method.

This example illustrates what is known as adapted site preparation, in which different measures are adapted to variations in site properties to reduce the risk of failure and to achieve optimal utilization of site productivity (Fryk 1986).

Table 4. Effect on scarification costs of increasing final volume on a site-specific basis.

Site class (Black spruce)	NPV ($/ha)	Site prep. costs ($/ha)	Site prep. costs, 10% vol. increase ($/ha)	Change in site prep costs (%)
I	-596	400	466	+16
Ia	-299	400	495	+24

Various difficulties and requirements are associated with adapted site preparation: highly qualified personnel are needed; planning can be time-consuming and expensive; the cost of carrying out the operation may be higher; equipment must be available at the right time and place; equipment does not always perform as expected and desired and, for some conditions, proper techniques have not yet been developed; and the optimal size of treatment units needs to be determined. A breakthrough in the practicability and economics of adapted site preparation depends on the development of machinery in which one unit (e.g., a Bräcke Cultivator Mounder or Donaren 280 Powered Disc Trencher) can be used to create various types of site preparation.

CONCLUSION

It is apparent that highly variable results are possible, either by design or by accident, if different mechanical site preparation treatments are applied. The challenge is to take advantage of the opportunities made possible by this variation. Knowledge of the constraints on seedling performance on different

sites, and an understanding of how to manipulate the key physical site factors so as to alleviate these constraints are fundamental to the improvement of site preparation practice.

Long-term research is essential for increasing knowledge. Although early survival and stocking evaluations continue to provide useful feedback on the success of treatments, information on the combined effects of survival and long-term (20+ years) growth and final yield is lacking. The biological feedback becomes even more important when one considers the array of site preparation equipment and treatments available today. Clearly, the equipment is more highly developed than is our understanding of the biological basis for its application.

Are we now in a better position to answer the question of how much effort and expense are warranted in attempting to meet or improve upon performance objectives? The financial analysis examples give some indication of this.

From a financial perspective, the examples indicate that a large difference in early stocking can result in large differences in NPV, the effect being greater on higher site classes. Hence, for normal levels of inputs/expenditures to stock a given site, greater care must be taken to guard against poor results and economically unsound operations. Caution is especially important on higher site classes, when considering such factors as site preparation prescriptions, machinery selection and application, and seedling placement. Conversely, it stands to reason that a more economically sound operation is attainable if everything goes right, and higher, earlier stocking than the minimum requirement is achieved. The serious economic consequences of failing to anticipate and guard against long-term problems such as chronic or catastrophic windfall should be obvious. From a wood supply perspective, relatively small gains in final yield (2-10%) may be sufficiently lucrative to compensate for significantly higher costs of site preparation undertaken to achieve better results.

In summary, time and effort devoted to better practice and biology appear to yield better returns. How much better? Until wide ranging and long-term research results are available, modellers and analysts will be unable to answer this question with precision. Does biology deserve top billing? Without a doubt!

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APPENDIX A

Definitions and Detailed Calculations for Examples 1, 2, and 3

Net Present Value (NPV) represents the sum of discounted[2] flows of **revenues** (positive values) and **expenditures** or costs (negative values).

NPV (gross operating profit) represents the net of discounted **harvesting revenues**, less discounted **harvesting and transportation** costs, expressed in terms of the anticipated average profit per hectare to be realized over the extent of the candidate area to be harvested.

NPV (gross profit on regeneration investment) represents the net of discounted **gross operating profits**, less discounted **plantation establishment, tending and management costs**, expressed in terms of the anticipated average profit per hectare to be realized over the extent of the candidate treatment area.

Harvesting revenues, expressed in terms of $ per hectare discounted to the present, represent the total of the volume harvested[3] in m^3/ha multiplied by the nominal mill gate price in $\$/m^3$.

Harvesting and transport costs, expressed in terms of $ per hectare, represent the anticipated area-averaged and discounted aggregate cost of harvesting, forwarding, loading, and transporting the harvested timber from the stump to the mill gate.

Plantation establishment, tending and management costs, expressed in terms of $ per hectare, represent the anticipated area-averaged and discounted aggregate cost of plantation establishment (inclusive of site-preparation costs) and the associated costs of plantation tending and management, from the time of plantation establishment to the realization of a marketable crop at presumed rotation.

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[2] The discount rate and the estimates for the real rate of increase in the costs of plantation establishment and tending, in the costs of harvesting and transport, and in the mill gate price are all assumed to be constant and equivalent at a rate of 4% per annum. Note that this is an arbitrary assignment and that equivalent rates were chosen solely for the purpose of simplifying the mathematical calculations of the following examples. In this case, equations 3 and 4 have been used for the relevant calculations. If different rates had been used, equations 1 and 2 would have been substituted for equations 3 and 4, respectively.

[3] from Table 1, in text

Equations used in calculations:

If we assume a fixed rotation period (R), a constant discount rate (i), and constant (non-varying) rates of change for mill gate price change (a); harvesting and transportation costs (b); and plantation establishment, tending and management costs (f) over the duration of the rotation period (R), then ...

Equation 1.

NPV gross operating profit (in $/ha) =

$$\left[\left[\frac{\text{volume harvested, in m}^3}{\text{area harvested, in ha}}\right]\left[\frac{\text{mill gate price, in \$/m}^3}{(1.0 + i)R \;/\; (1.0 + a)R}\right]\right]$$

minus

$$\left[\left[\frac{\text{volume harvested, in m}^3}{\text{area harvested, in ha}}\right]\left[\frac{\text{harvesting and transportation costs, in \$/m}^3}{(1.0 + i)R \;/\; (1.0 + b)R}\right]\right]$$

Equation 2.

NPV gross profit on regeneration investment (in $/ha) =

$$\left[\left[\text{NPV gross operating profit, in \$ /ha}\right] - \left[\sum_{s=1}^{S}\left[\frac{\text{plantation establishment, tending, and management costs, in \$/ha}}{(1.0 + i)'(s) \;/\; (1.0 + \phi)'(s)}\right]\right]\right]$$

where:

t(s) represents silvicultural treatment (s), at time (t), in years

S represents the total number of silvicultural treatments undertaken (i.e., establishment, tending, and/or management)

s represents silvicultural treatment

If we assume a fixed rotation period (R), a constant discount rate (i), and constant rates of change of mill gate price change (α); harvesting and transportation costs (β); and plantation establishment, tending and management costs (ϕ) over the duration of the rotation period (R), and that the discount rate, and the rates of price and cost change are all equivalent (i.e., that $i = \alpha = \beta = \phi$), then ...

Equation 3.

NPV gross operating profit (in \$/ha) =

$$\left[\left[\frac{\text{volume harvested, in m}^3}{\text{area harvested, in ha}}\right]\left[\text{mill gate price, in \$/m}^3\right] - \left[\text{harvesting and transportation costs, in \$/m}^3\right]\right]$$

Equation 4.

NPV gross profit on regeneration investment (in \$/ha) =

$$\left[\left[\text{NPV gross operating profit, in \$/ha}\right] - \left[\text{plantation establishment tending and management costs, in \$/ha}\right]\right]$$

Example 1.

NPV gross operating profit[4] at age 60, predicated by stocking[5] at age 10:

40% stocking:	[(196 m^3/ha) * ($5.00/$m^3$)] =	$980/ha
65% stocking:	[(238 m^3/ha) * ($5.00/$m^3$)] =	$1190/ha
90% stocking:	[(256 m^3/ha) * ($5.00/$m^3$)] =	$1280/ha

Discounted expenditures[6] for plantation establishment, tending and management:

i) mechanical scarification ..... = $150/ha
ii) bare-root planting, including cost of stock .... = $800/ha
iii) aerial herbicide tending (combined herbicide and application costs) three years after planting ..... = $130/ha
iv) miscellaneous costs at various intervals over the rotation age (i.e., survival and free-to-grow estimates, cruise and marking prior to harvest) ..... = $35/ha

NPV gross profit on regeneration investment, predicated by stocking at age 10:

40% stocking:	[980 - (150 + 800 + 130 + 35)] =	$-135/ha
65% stocking:	[1190 - (150 + 800 + 130 + 35)] =	$75/ha
90% stocking:	[1280 - (150 + 800 + 130 + 35)] =	$165/ha

Example 2.

NPV gross operating profit at age 60, predicated by stocking at age 10:

<u>Site class II</u>		
65% stocking:	[(155 m^3/ha) * ($5.00/$m^3$)] =	$775/ha
75% stocking:	[(158 m^3/ha) * ($5.00/$m^3$)] =	$790/ha
<u>Site class I</u>		
65 % stocking:	[(238 m^3/ha) * ($5.00/$m^3$)] =	$1190/ha
75 % stocking:	[(248 m^3/ha) * ($5.00/$m^3$)] =	$1240/ha

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[4] The difference, expressed in terms of $/$m^3$, between the mill gate price and the combined cost of harvesting and transportation is assumed to be constant (regardless of the per-hectare volume harvested) and equivalent to a discounted value of $5.00/$m^3$.

[5] based on a 2 m x2 m quadrat.

[6]. based on average costs for plantation establishment, tending and management in the Northwestern Region (CNWR).

Discounted expenditures for plantation establishment, tending and management:

i) mechanical scarification ..... = $150/ha
ii) aerial seeding ..... = $50/ha
iii) precommercial spacing (brush saw) nine years after planting ..... = $300/ha
iv) miscellaneous costs at various intervals over the rotation age (i.e., survival and free-to-grow estimates, cruise and marking prior to harvest) ..... = $35/ha

NPV gross profit on regeneration investment, predicated by stocking at age 10:

Site class II

65% stocking: [775 - (150 + 50 + 300 + 35)] = $240/ha
75% stocking: [790 - (150 + 50 + 300 + 35)] = $255/ha

Site class I

65% stocking: [1190 - (150 + 50 + 300 + 35)] = $655/ha
75% stocking: [1240 - (150 + 50 + 300 + 35)] = $705/ha

Maximum site preparation costs (X), to achieve an equivalent NPV result, as obtained at the 65 % stocking level at age 10, but attainment of a 75% stocking level at age 10 is presumed (with increased expenditure on site preparation):

Site class II:

[(158 m³/ha * $5.00/m³) - (X + 50 + 300 + 35)] = $240/ha
solving for X, then maximum site preparation costs = $165/ha

Site class I:

[(248 m³/ha * $5.00/m³) - (X + 50 + 300 + 35)] = $655/ha
solving for X, then maximum site preparation costs = $200/ha

Example 3.

From black spruce variable-density yield tables based on managed plantations in the Northwestern Region[7], gross merchantable volume at age 60, fully stocked (at a 2 m x 2 m spacing) amounts to 190 m³/ha for site class I, and to 270 m³/ha for site class Ia.

NPV gross operating profit at age 60:

Site class I

i) If we assume the realization of 70% of the fully stocked volume:

[(0.70 * 190 m³/ha) * ($ 5.00/m³)] = $665/ha

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[7]. Willcocks, A.J., Bell, S.W., Williams, J. 1988. Establishing spacing regimes and rotation for conifer species -- a northern Ontario case study. Ont. Min. Nat. Resour., Northwestern Ont. For. Tech. Dev. Unit. (in preparation)

ii) assuming the realization of a 10% increase in volume:
[((0.70 + (0.10 * 0.70)) * 190 m³/ha) * ($5.00/m³)] = $731/ha

Site class Ia

i) If we assume the realization of 70% of the fully stocked volume:

[(0.70 * 270 m³/ha) * ($5.00/m³)] = $945/ha

ii) assuming the realization of a 10% increase in volume:

[((0.70 + (0.10 * 0.70)) * 270 m³/ha) * ($5.00/m³)]= $1040/ha

Discounted expenditures for plantation establishment, tending and management:

i) mechanical scarification ..... = $400/ha
ii) container planting including cost of stock ... = $710/ha
iii) aerial herbicide tending (combined herbicide and application costs) three years after planting..= $116/ha
iv) miscellaneous costs at various intervals over the rotation age (i.e., survival and free-to-grow estimates, cruise and marking prior to harvest) ..... = $ 35/ha

NPV gross profit on regeneration investment, at 70 % of fully stocked volume:

Site class I:
[665 - (400 + 710 + 116 + 35)] ..... = $-596/ha

Site class Ia:
[945 - (400 + 710 + 116 + 35)] ..... = $-316/ha

Maximum site preparation (X), to achieve an equivalent NPV result, as obtained at the 70 % fully stocked volume level, the attainment of a 10 % increase in volume at age 60 presumed (with increased expenditure on site preparation):

Site class I:

[((133.0 + 13.3) * 5.00) - (X + 710 + 116 + 35)] = $-596/ha
solving for X, then maximum site preparation costs = $466/ha

Site index Ia:

[((189.0 + 18.9) * 5.00) - (X + 710 + 116 + 35)] = $-316/ha
solving for X, then maximum site preparation costs = $495/ha

Effects of Site Preparation and Full Tree Logging on Nutrient Cycling

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Abstract

Theoretical estimates of nutrient removals from jack pine, black spruce, and aspen forests during tree harvesting and site preparation were determined for sites representative of the boreal forest of Ontario. Nutrient removals by conventional (stems-only) and full tree harvesting, for a range of sites, and N displacement based on the most severe site disturbance that might be produced by shear-piling, ploughing and prescribed burning, on two selected sites, were assessed on the basis of published information on site nutrient capitals. Average gains of 20 to 50% in phytomass recovery were achieved by full tree logging, at the expense of >100% increases in removal of N, P, K and Mg from jack pine and aspen sites and up to 175% increases in nutrient extraction from black spruce sites. Nitrogen displacement from boreal sites as a result of shear-piling may be as much as 750 to 835 kg N/ha; equal to 10 times that associated with bolewood harvesting of jack pine and 6 times that in the case of black spruce. An additional displacement of 150 to 250 kg N/ha from the rooting zone might result if deep ploughing were done on windrowed sites. Even if actual nutrient displacement is somewhat less than predicted, the magnitude of the potential removal raises concern about the possibility that shear-pile treatments and deep ploughing could reduce site productivity on many boreal sites.

Introduction

The operational and silvicultural advantages of mechanical site preparation are well known. Benefits include improved site

accessibility and ease of planting, less competing vegetation and creation of improved conditions for regeneration and vigorous root development of young trees. Tree harvesting, slash removal and site preparation also reduce the nutrient capital of forest ecosystems. The challenge in the managed forest, therefore, is to meet operational needs by obtaining successful regeneration, without sacrificing the future productivity of the system by depletion of site organic matter and nutrient reserves.

By means of a case study we will stress the nutritional problems associated with removal of organic matter from the forest floor during harvesting and site preparation. Organic matter ensures moisture retention, the presence of microbial substrates and buffering of nutrient supply. Significant reductions in organic matter and nutrients may result in a reduction in total site productivity that does not become evident until later in the rotation. Strategies for maintaining long-term organic matter and nutrient supply of soils will be discussed.

Most consideration will be given to the nitrogen (N) nutrition of jack pine (Pinus banksiana Lamb.), black spruce (Picea mariana [Mill.] B.S.P.) and, to a lesser extent, aspen (Populus tremuloides Michx.) forests, largely on sites representative of the boreal forest of Ontario. Many boreal forests are limited in N and, hence, N removal poses more of a threat to long-term productivity than does removal of other nutrients.

Disturbance, which has such an important role in the dynamics of boreal forests, is particularly significant with respect to nutrient cycling. Canopy removal increases radiant energy at the ground level. This raises soil temperature and accelerates decomposition, which is necessary for recycling nutrients incorporated in organic layers. The increased nutrient availability in cutover soils favours a rapid growth of regeneration and a general recovery of ecosystem processes. On richer sites, canopy removal and increased nutrient availability might also encourage brush competition, with corresponding growth reductions in crop

regeneration. In the natural state, release of the nutrients contained in the forest floor organic layers is often dependent on cycling through fire disturbance. A severe fire, in addition to favouring rapid mineralization of many nutrients, can contribute to a reduction in the N capital of a site. In the managed forest, the organic matter and nutrient content of the soil can be manipulated by site preparation techniques such as prescribed burning, shear-piling and ploughing, to avoid potential losses in future forest productivity.

Site Nutrient Reserves

At boreal latitudes, forest floor temperatures in undisturbed forest are below the optimum for decomposition of organic matter, and N accumulates in the forest floor organic layers. Nutrient contents of vegetation, forest floor and mineral soil (to a 30-cm depth) prior to harvest are presented for aspen, jack pine and black spruce forests, largely in Ontario and Quebec, in Table 1. The mean N contents of the forest floor of mature forest were 425, 500 and 1165 kg/ha for aspen, jack pine and black spruce, respectively. Forest floor N, together with aboveground phytomass N in trees, represents a major reservoir of N in these forest types, i.e., 21, 28 and 51% of the total ecosystem N content.

Nutrient accumulation in tree phytomass and in litter on the forest floor is site specific. Differences in stand nutrient (i.e., N) contents of up to three times in pine and aspen woodland and seven times in black spruce forest are related to age and site quality. For Ontario and Quebec, the ratio of nutrient accumulation to total ecosystem N contents within species is relatively uniform, in contrast with the difference in the ratios between species. Sites with large ratios have a high proportion of their N reserves in live and decaying organic matter, and the trees may be more dependent on the organic layers for their N nutrition. Black spruce sites in Alaska and the Maritimes ex-

hibited much smaller ratios than those in Ontario and Quebec. These results suggest that this ratio may be characteristic of the species only within climatic regions.

There was a significant linear relationship (r^2 = 0.78 and 0.80, respectively) between the amount and N content of jack pine phytomass and the N content of the soil (Fig. 1a,b). Jack pine responded well to N fertilization; better growth responses were observed on a less fertile sand than on a richer till (Table 2). Reducing soil N contents, therefore, may result in less phytomass productivity over time. Further, cultural techniques with a potential for removing large amounts of N from the site should be avoided if site quality is to be maintained.

The amount and N content of black spruce phytomass were also linearly related (r^2 = 0.76 and 0.50, respectively) to soil N contents (Fig. 1c,d). If we assume that a true relationship exists, soil N content explained less of the variation in N uptake than it did in pine. Modest growth responses to N fertilizers and to other nutrient additions have been reported for black spruce (Table 2, Krause et al. 1982). Factors other than nutrition appear to be controlling the growth of black spruce on some sites; hence, the consequences of N removal from such sites remain less clear.

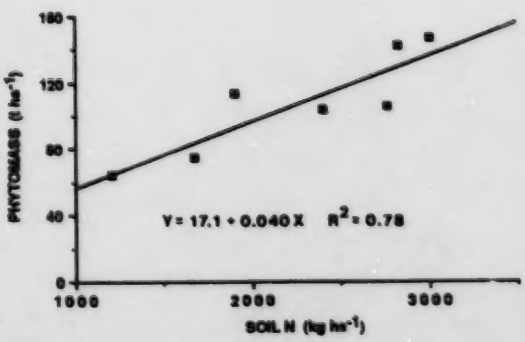

Figure 1a.

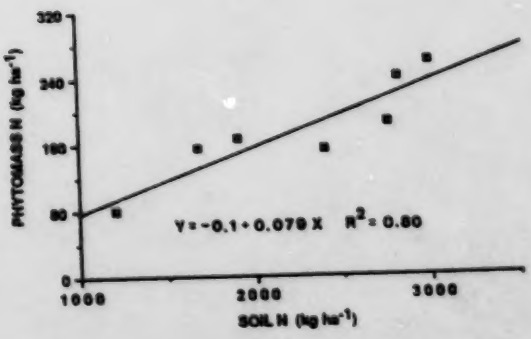

Figure 1b.

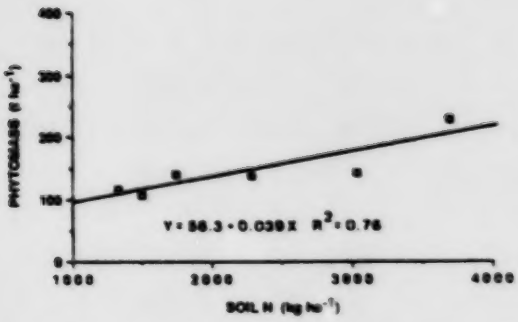

Figure 1c.

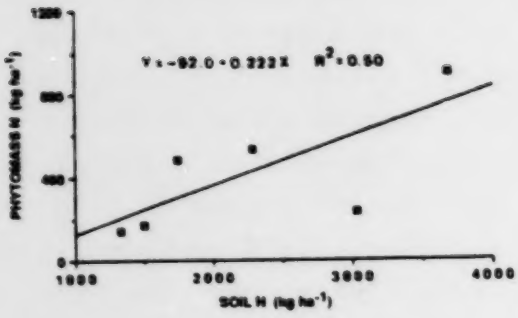

Figure 1d.

Figure 1. The relationship between phytomass and N accumulation in jack pine (1a, 1b) and black spruce (1c, 1d) and soil N contents.

Table 1. The dry-matter and nitrogen content of boreal species.

Age (yr)	Basal area (m^2/ha)	Site	Aboveground phytomass (t/ha)	Aboveground N (kg/ha)	Forest floor N (kg/ha)	Mineral soil N (kg/ha)	Ecosystem N content (kg/ha)	N^a ratio	Reference/Region
					Jack pine				
48	31	sil loess	113	167	398	1505	2070	0.27	Foster and Morrison 1982, Ontario
55	21	sand	104	153	632	1768	2553	0.31	Morrison and Foster 1974, Ontario
55	32	SL till	142	240	535	2295	3070	0.25	Morrison and Foster 1974, Ontario
65	24	sand	106	185	430	2330	2945	0.21	Foster and Morrison 1976, Ontario
57	25	till	75	155	619	1053	1827	0.42	Maclean and Wein 1977, New Brunswick
53	-	sand	65	81	200	1000	1281	0.22	Westman and Algar 1983, Quebec
40	35	SL till	147	259	689	2312	3260	0.29	Alban et al. 1978, Minnesota
x 53	28		107	177	500	1752	2429	0.28	
					Black spruce				
48	33	sand	141	482	1050	695	2227	0.69	Gordon 1983, Ontario
65	42	SL till	107	167	1200	300	1667	0.82	Westman and Webber 1972, Quebec
75	28	SL till	113	240	647	3281	4168	0.21	Freedman et al. 1986, Nova Scotia
95	25	sil loess	50	123	630	3070	3823	0.20	Van Cleve et al. 1983, Alaska
110	23	L till	142	234	1790	1240	3264	0.62	Foster and Morrison 1987, Ontario
126	32	SL till	138	536	1302	982	2820	0.65	Timmer et al. 1983, Ontario
126	49	SL till	225	897	1849	1827	4573	0.60	Timmer et al. 1983, Ontario
200	-	humus\ bedrock	116	140	860	470	1470	0.68	Westman and Algar 1983, Quebec
x 106	33		129	352	1166	1483	3001	0.68[b]	

(cont'd)

Table 1. The dry-matter and nitrogen content of boreal species. (concl.)

Age (yr)	Basal area (m^2/ha)	Site	Aboveground phytomass (t/ha)	Aboveground N (kg/ha)	Forest floor N (kg/ha)	Mineral soil N (kg/ha)	Ecosystem N content (kg/ha)	N[a] ratio	Reference/Region
					Aspen				
39	32	sand	160	602	-	6371	6973	-	Timmer et al. 1983, Ontario
40	32	SL till	167	368	667	2058	3093	0.33	Alban et al. 1978, Minnesota
65	32	SL	198	350	41	3200	3591	0.11	Pastor and Bockheim 1984, Wisconsin
55	34	sil loess	110	266	690	2410	3366	0.28	Van Cleve et al. 1983, Alaska
75	18	SL till	64	185	303	3625	4113	0.12	Freedman et al. 1986, Nova Scotia
x 55	30		140	354	425	3533	4227	0.20	

[a] Ratio of N accumulation in phytomass plus forest floor to that in the ecosystem.

[b] Quebec-Ontario sites only

Table 2. Growth response of coniferous forest in northern Ontario to fertilization.

Nitrogen (kg/ha)	Total volume increment (m^3/ha)	Total volume growth above that of the control (m^3/ha)	(%)
	Jack pine - Avery till[a]		
0	19.9	-	-
76	21.6	+1.7	8.5
303	25.0	+5.1	25.6
	Jack pine - Stokes sand[a]		
0	16.5	-	-
84	22.0	+5.5	33.3
252	27.0	+10.5	63.6
	Black spruce - till[b]		
0	26.2	-	-
112	30.5	+4.3	16.4
336	31.0	+4.8	18.3

[a] four-year growth responses cited from Morrison et al. 1976

[b] five-year growth responses cited from Foster et al. 1986

Nutrient Removals by Harvesting

The average nutrient removal by conventional (stems-only) harvesting was greatest in aspen, intermediate in black spruce and least in jack pine forest (Table 3). Calcium (Ca) and N were generally the elements removed in the largest quantity in both conventional and full tree (stems plus crowns) logging. Considerably more phytomass and nutrients were removed by full tree harvesting than by conventional logging. Average gains in phytomass recovery of 20 to 50% were achieved at the expense of >100% increases in N, phosphorus (P), potassium (K) and magnesium (Mg) removal from jack pine and aspen sites and up to 175% increases

Table 3. Quantitites phytomass and nutrients removed from boreal forests by harvesting.

Species	Harvesting method	Phytomass (t/ha)	N	P	K	Ca	Mg
			(kg/ha)				
Jack pine (n = 6)	conventional	85	75	6	49	97	15
	full tree	110	175	17	88	160	26
Black spruce (n = 7)	conventional	81	137	19	44	352	22
	full tree	124	333	42	121	604	47
Aspen (n = 5)	conventional	108	181	20	148	410	35
	full tree	136	352	40	237	649	59

in nutrient extraction from black spruce sites. Increases in Ca removal were proportionally somewhat less (50 to 70%). In aspen and black spruce, however, the absolute quantities of Ca derived exceeded the additional extraction of any other individual nutrient.

Patterns of nutrient depletion reflect the relative distribution of nutrients among tree components. In the conifers the canopy is the major N sink, followed by the stem and the roots (Fig. 2). The proportion of N in the canopy was largest for black spruce and smallest for aspen. In all three species the proportional distribution of Ca among components was similar and the stem was the major sink for Ca, followed by the crown and the roots.

During forest harvesting, forest floor layers are commonly disturbed and often displaced. Organic layers ensure moisture and nutrient retention and provide a favourable substrate for microbial mineralization of N. Most of the nutrient retention capacity of sandy soils is a result of organic matter. This suggests that infertile sites should be managed with an aim to conserving carbon (C) and N reserves. Losses of humified organic matter from soils after harvesting may be negligible if increased soil respiration and reduced annual litter inputs are offset by

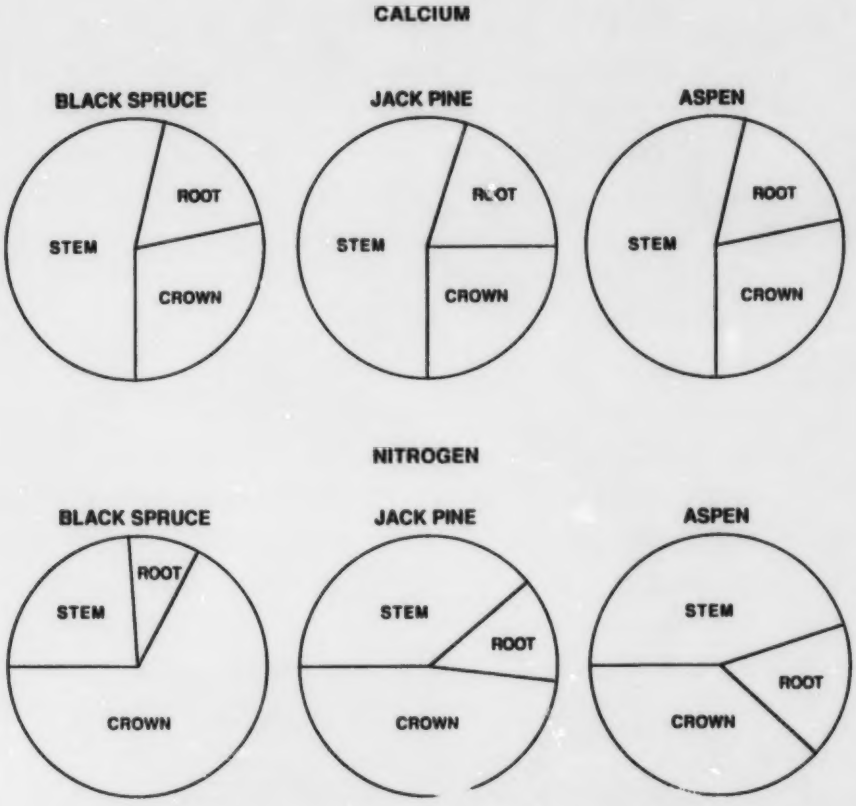

Figure 2. Proportions of N and Ca in phytomass components of aspen, pine and spruce-dominated stands (Source: Foster and Morrison 1976, 1987; Pastor and Bockheim 1984).

organic matter inputs in slash and decaying roots. Maintaining logging residues and litter on site has been shown to favour N uptake and promote the greater growth of radiata pine (Pinus radiata D. Don) in Australia (Farrell et al. 1986). Retention of forest floor nutrients on site may be essential both to promote short-term postharvest nutrient availability and to maintain long-term soil fertility.

Nutrient Removals by Site Preparation

Little information is available for boreal sites on nutrient disturbance after site preparation by shear-piling, shear-piling

and ploughing (deep ploughing), or fire. It was necessary, therefore, to proportion the effects of treatment on the basis of reported nutrient disturbance when similar scarification techniques were applied in other regions. In this comparison, we assumed that 50% of the total N content of the slash and forest floor (L and F layers) and 20% of the N in the H layer and surface 2 cm of mineral soil would be eliminated by burning at a medium fire intensity (MacLean and Wein 1980). Removal of slash and 5 cm of the surface soil was assumed for shear-pile calculations (Haines et al. 1975). Deep ploughing was assumed to follow windrowing and to result in displacement of 7 cm of infertile subsoil to the surface, thereby displacing an equivalent amount of fertile B horizon soil beyond the effective rooting zone. Potential N removals produced by site preparation after conventional harvesting were estimated on the assumption of the most severe site disturbance possible, for two selected sites; a 55 year old jack pine and a 110 year old black spruce stand (Table 4).

(a) Shear-piling

Shear blades and rakes are used to remove surface debris from the planting area and to pile debris into windrows for burning. The shear-pile treatment uses angled or V-shaped tractor mounted blades to cut large unmerchantable stems that remain on site after harvesting. Nitrogen displaced by shear-piling would appear to have a very great impact on site N reserves. This is consistent with the findings in other studies, largely in the southern United States (Morris et al. 1983, Tew et al. 1986). The estimated quantities of nutrients removed from boreal sites, however, exceeded those (375 to 715 kg N/ha) observed on southern pine sites (ibid.).

In windrowing, large portions of the biologically active, nutrient rich organic layers and surface mineral horizons may be removed along with the stumps and branches (Morris et al. 1983). Nutrient losses from boreal sites as a result of windrowing may

be as large as 750 to 835 kg N ha-1, equal to 10 times those removed in bolewood harvest of jack pine and 6 times those in black spruce. The displacement of forest floor N to windrows in the shear-pile treatment would significantly reduce nutrient reserves after site preparation on the sites occupied by each species. Such nutrient losses can be reduced considerably by employing flexible tooth rakes that remove slash and produce less disturbance of the organic layers.

(b) Burning

Chopping/burning displaces less organic matter and N and exposes less mineral soil than shear-pile or shear-pile/discing treatments in the Piedmont and Upper Coastal Plain of the southeastern United States (Gent et al. 1984, Pehl 1984). We suggest, on the basis of our calculations, that considerably less N would

Table 4. Nitrogen removal (kg/ha) associated with site preparation.

	Jack pine			Black spruce		
Fire	Shear-pile	Deep ploughing[a]		Fire	Shear-pile	Deep ploughing[a]
Slash	40	80	80	85	170	170
Forest floor	261	630	630	657	584	584
Mineral soil	25	124	294	26	0	245
Total	326	834	1004	768	754	999

[a] after shear-piling

be removed from jack pine sites by a medium intensity prescribed burn than by shear-piling (Table 4). More N was consumed by fire on the black spruce site because of its thicker organic layers. In black spruce forest, the quantities of N removed by shear-piling and burning were similar. A site preparation burn may

eliminate slash and logging debris without consuming a large portion of the forest floor and the N contained therein (Fox et al. 1986). Losses of N from the forest floor may be balanced by increased N contents in the mineral soil (Alban 1977). Furthermore, seedling nutrition may actually benefit if short-term increases in N availability occur after burning (e.g., Ryan and Covington 1986). However, site preparation that includes burning may also result in organic matter conversion to charcoal. Charcoal can remain unoxidized for long periods, thereby reducing the nutrient retention capability of a site. Alternatives to prescribed burning which are less severe site preparation treatments than shear-piling and are commonly practised in the boreal forest region today are disc trenching and patch scarification.

(c) Ploughing

When heavy slash presents difficulties, powered choppers are preferable to shear blades. Pehl (1984) has pointed out that, "Unlike the shear-pile treatments, however, the chopping treatment does not remove or invert the surface horizon; rather it crushes and chops the organic material into the soil, with minimal disturbance." Chopping and ploughing to incorporate slash into the upper 10-15 cm of soil, therefore, is a desirable method of land clearing, although operational or economic constraints may restrict its application. The objective here is to mix organic layers with the mineral horizons in which the nutrients are concentrated, i.e., surface mineral horizons (Fig. 3). Mixing of mineral soil and organic layers provides the best seedbed for moisture and nutrient retention and enhances the rate of humus decomposition (Salonius 1983). The importance of maximizing the water retention capacity of the soil on excessively drained soils cannot be overemphasized. After a tree is outplanted, its initial survival is highly dependent on its ability to obtain sufficient water to avoid desiccation. Rooting medium fertility is equally important in ensuring rapid root regeneration and securing survival of newly planted trees.

Choppers, however, are likely to be of limited use on the shallow, stony tills that represent a large proportion of the land base of northern Ontario. On this terrain, disc trenching is a popular method of mechanical site preparation. Disc trenchers produce furrows bordered by berms of inverted and partially mixed surface soil. Because soil mixing is far from complete in the berm, tree seedlings may not be able to take advantage of the nutrients in inverted humus layers during their initial growth.

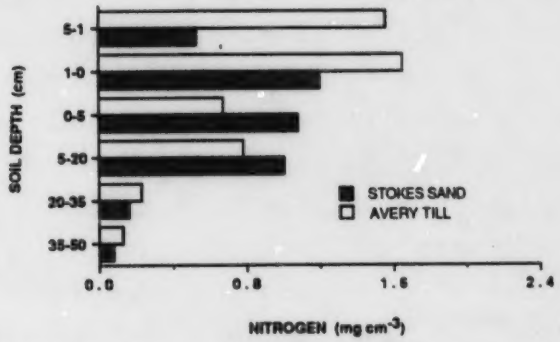

Figure 3. Nitrogen concentrations in organic layers and mineral soil from a 55 year old jack pine stand on a glacio-fluvial sand (Stokes) and a sandy loam till (Avery), respectively (derived from Morrison and Foster 1974).

On moist and wet sites with medium textured soils, mounds may be required to facilitate drainage, raise soil temperatures and provide nutrients in the inverted humus layers. For example, McMinn (1985) has reported that the initial third year growth and second year N uptake by white spruce (Picea glauca [Moench] Voss) seedlings on inverted mounds exceeded that by seedlings on untreated and blade scarified scalped patches. Furthermore, on fertile, medium textured sites, the site preparation treatments must eliminate undesirable vegetation or inverting will stimulate competing species (ibid.).

Total N contents in the mineral soil after chopping and discing may increase as a result of incorporation of slash and forest floor organics into mineral horizons (Fox et al. 1986).

The inherent danger in ploughing too deep on boreal sites is the larger loss of N from mineral soil than is produced by burning or shear-pile treatments (Table 4). The largest displacement of nutrients from the site could result from the combination of shear-pile treatments and deep ploughing.

Summary

Nutrient budget calculations presented in this paper strongly indicate that retention of the forest floor nutrient contents on site should be one objective of site preparation treatments. Weber et al. (1985) have demonstrated that a single removal of organic layers from an infertile 50 year old jack pine site reduced foliar N concentrations and produced a 30% reduction in radial tree growth eight years after treatment. On the other hand, the loss of nutrients in surface organic layers as a result of intensive mechanical site preparation techniques, such as shear-pile treatments, may have little effect on seedling growth and nutrient uptake on soils with high inherent fertility (Pehl 1984).

From the nutritional point of view, scarification equipment that penetrates deep into the mineral soil should be avoided on infertile sites. Equipment that cultivates the top 10 to 15 cm of soil, mixing rather than scraping off the topsoil, should be favoured. Shear-piling may be the only practicable method of achieving satisfying site preparation under some conditions, e.g., when unregenerated land with considerable amounts of competing vegetation is being treated or when hardwood forest is being converted to conifer plantations. As Morris et al. (1983) have indicated: "In these instances soil disturbance and nutrient displacement can be minimized by shortening the distance between windrows and decreasing their size." Strategies for maintaining the long-term nutrient supply of soil include:

(a) retaining slash where possible;

(b) mixing organic layers with mineral horizons to enhance nutrient and moisture retention;

(c) avoiding shortening the rotation length so that nutrient inputs from precipitation, N fixation and mineral weathering are maximized.

Good estimates of nutrient losses and displacements associated with site preparation are not always readily available for boreal site types and are often difficult to predict. We have assembled nutrient budget information for aspen, black spruce, and jack pine ecosystems in an attempt to determine whether site preparation might change site nutrient reserves and thereby affect site productivity. Estimates of potential N removal associated with severe site disturbance after site preparation on cutover jack pine and black spruce forests greatly exceeded those related to conventional (stems only) or full tree harvesting. Concern that excessive nutrient drain associated with shear-piling will remove organic layers, and that deep ploughing will reduce site productivity on many boreal sites appears well founded. Chopping or chopping/burning is a preferable method of site preparation on infertile sites, because of the potential loss of productivity that could result if shear-piling disturbs organic layers and displaces N. There are other site preparation alternatives to burning or chopping (e.g., disc trenching and patch scarifying) that are much less drastic in their effects than shear blading and piling. Potential nutrient disturbances discussed in this paper should be substantiated by measurement of soil nutrient contents after site preparation.

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Cold Soils

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Synopsis

This paper summarizes some Swedish studies into water and temperature relations in different soil types and how these are affected by site preparation

Söderström's Studies

As a background, a discussion follows of some results from north Sweden by Söderström, 1986.

Generally, (in north Sweden with its maritime climate) the mortality of young trees is high during wet summers. The reason for this is that the water uptake of the trees is limited due to a lack of oxygen and low temperatures. Besides the necessity to remove the moisture surplus in the northern areas, it is important to increase the soil temperature. The optimum temperature for root growth of scots pine is about 30°C and for norway spruce about 25°C.

In north Sweden such high temperatures are not achieved at 10 cm. depth in untreated soil and seldom in scalped spots, or in shoulders after ploughing. In north Finland, the low soil temperature is in the same way a factor that influences the growth of trees.

Lähde's Studies

In his paper "Effects of soil treatment on physical properties of the soil and development of scots pine and norway spruce seedlings", published 1978, Lähde deals with the relationship of moisture and temperature in the soil.

The experimental areas were in north Finland at very high latitudes 66°17' N to 67°51' N, and at altitudes between 200-300

metres above sea level. Soil treatments included scalping, herbicides, scalping by burning, 30 cm soil transfer, 10 cm soil transfer, shoulder (terrace) ploughing, V-trench ploughing, complete tilling, chain rototilling, ploughing plus chair rototilling, and untreated.

Lähde's results:

A series of Lähde's charts shows generally that:

1. seedling height improves with increasing soil degree days;
2. seedling height improves with increasing soil air space;
3. seedling height improves with decreasing soil water content;
4. seedling height improves with decreasing soil bulk density.

The soil was most porous in the treatments where humus had been mixed with mineral soil and where mineral soil had been lifted into mounds on top of the humus and ground cover. Such treatments were:

10 cm transferred layer;
V-trench ploughing;
complete tilling;
chain rototilling;
ploughing plus chain rototilling.

The most northern experimental area had large areas of fine texture soils (about 40% particles ≤ 0.06 mm), which strongly retain water. Here the untreated, scalped, and ploughed shoulder soils at times had too little airspace for the roots to function effectively. Sometimes, at the beginning of the study the air space was less than 10% of the volume.

In sandy soil, at another location about 10 km east of the first location, no problems were caused by limited air space. Air space was increased considerably by effective soil treatment

where humus was mixed with mineral soil and where mounds of mineral soil were formed on top of the humus.

Even though the air space was very large in these treatments (in chain rototilling as high as 70% of the soil volume) the soil usually was not too dry. Lack of water at an average depth of 5 cm was not a problem on the studied areas, even with the most effective soil treatment.

The soil treatments which provided the best planting spots with respect to soil structure, water and air conditions were also the warmest.

In the early summer the soil warmed up much faster in the V-trench ploughing than in the shoulder ploughing, patches, and untreated soil.

At the most northern site, the 10 cm soil layer on top of the humus layer, the chain rototilled, and ploughed plus chain rototilled treatments warmed up even faster than the V-trench ploughing treatment. Due to rapid heating, the number of degree days in the soil of these treatments was considerably higher than in the patches or untreated soils.

With effective soil treatment, the number of degree days in the soil could be increased so much that, for example, the V-trench treatment when compared to patches, corresponded to conditions located 200-300 km farther south or 150-200 m lower altitude.

(Editor's note - A complete set of Prof. Bergman's presentation overhead slides may be obtained by contacting the Northwestern Ontario Forest Technology Development Unit.)

Long Term Effects of Site Preparation In Northern Europe

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This paper will discuss some aspects of site preparation in relation to stand productivity. Swedish and Finnish experience on potential deleterious effects of harsh site preparation on soil nutrient reserves and subsequent stand growth will be emphasized.

Relatively little is known about the long term effects of site preparation. Fennoscandian site preparation research has mostly concentrated on short term establishment. Older studies are few and often have poor design or have not been followed up. Fennoscandian views on long term effects have been influenced by a small number of old experiments, European experience and conclusions from short term research.

The Historical Development of Site Preparation

The practice of site preparation has been around for a long time in Fennoscandia though it was not done on a large scale until timber production escalated following World War II. Until then artificial regeneration measures were limited and selection system logging was common. Mechanized site preparation became popular following the decline of prescribed burning and the introduction of skidders and forwarders in the 1960's.

Developments in mechanization and expansion of timber production in the 1960's and 1970's led to large areas being mechanically site prepared. The weevil Hylobius abietis has had a major negative effect on forest regeneration and exposure of mineral soil has been an important means of reducing this risk. A great deal of research was carried out in the 1970's investigating the effects of site preparation on seedling establishment and physical soil characteristics. Many studies indicated the best

results with intensive treatments such as ploughing, that raised soil temperatures (exposed mineral soil), improved drainage and aeration, reduced vegetative competition and provided favourable nutrient status. It was well known that some harsh site preparation methods were required on wet, cold, thick humus sites.

By the early 1980's, disc trenching had become the dominant operational site preparation treatment in Sweden and central and southern Finland. Concern arose, especially in Sweden, that routine application of relatively harsh treatments (ie. disc trenching) over a range of site types may deleteriously affect stand productivity. Large experiments were established in Sweden (eg. Hunt, 1987) and Finland (eg. Mälkönen et al., 1986) in the early 1980's to investigate the effects of site preparation treatments on different sites over the rotation period.

European Experience

Some European studies had indicated that initial benefits associated with intensive site preparation were not sustained and may be detrimental to longer term growth (eg. Neckelman, 1976; Leek, 1979).

As early as 1926 in Germany, Wittich (Rehfuess, 1978) showed significant losses of humus and nitrogen with deep ploughing compared with untreated controls. Later studies indicated even larger nitrogen losses with mixing of the soil as with roto-tilling (Table 1).

Table 1. An example of nitrogen losses 8 years after site preparation in north-eastern Bavaria. Fine textured soil, pseudogley soil type. (After Burschel et al., 1977.)

	% Loss of total N
Untreated	14
Deep ploughing, 40 cm deep	22
Roto-tilling, 20 cm deep	31

German experiments also indicated successful treatments for improving soil conditions. Deep ploughing or roto-tilling in combination with application of lime and phosphorous or planting of lupines or alder may lead to increased nitrogen and humus capital (Hetsch et al., 1981, cf. Lundmark & Nömmik, 1984). Deep ploughing provides benefits in terms of greater volumes of loosened soil which promotes deeper root penetration and subsequent improvements in water and nutrient uptake (Hochtanner and Seitschek, 1964; Hetsch et al., 1981). Intensive site preparation combined with measures to build up the humus layer are especially critical for the long term productivity on sandy soils where large humus and nitrogen losses can occur (Rehfuess, 1978).

British studies also indicate that initial benefits of intensive site preparation are not maintained (Thompson & Neustein, 1973). In a milestone Scottish study of intensive cultivation on an upland heath, Wilson & Pyatt (1984) identified three growth phases. During the first 8 to 10 years intensive cultivation treatments produced rapid height growth but this trend was generally reversed in the next 10 years. After 20 years there was a slight recovery in growth but no significant differences between treatments.

Fennoscandian Experience

In Sweden and Finland, concern for long term stand productivity and pressure from environmentalists has recently reduced the area that is intensively site prepared (ie. ploughing and disc trenching). Recent developments in site preparation technology include adjustments for downward pressure, angle of cultivation, rotation speed (or direction) along with intermittent or continuous options. Newer scarifiers can provide elevated planting positions as well as a range of microsites (eg. patch, trench). Hence it is possible to continuously adapt treatments to variations in site qualities (eg. moisture, humus thickness, slash, soil texture). Thus a properly trained and

motivated operator could provide very site specific treatments which should reduce the risk of regeneration failure and maintain or enhance the site's productive capacity.

The effects of site preparation on the long term site productivity are mostly influenced by changes in site hydrology and the intensity of liberation of available nutrients from organic material (Lundmark, 1985; Bäcke et al., 1986). The intensity of site preparation is reflected in the proportion of area that is disturbed as shown in Table 2.

Table 2. Distribution of affected soil area (%) with mounding, disc trenching, and ploughing (ca 2 m spacing). (After Lundmark, 1985.)

Site preparation method	Exposed mineral soil under original soil level	Exposed mineral soil over inverted humus	Raised or disturbed humus	Total disturbed area (%)
Inverted humus mound	14	10	11	35
Disc trench	21	14	19	54
Plough	26	33	10	69

The degree of ditching and increase in surface run-off would affect the site hydrology. Continuous cultivating equipment such as ploughs or disc trenchers may create water deficiency conditions for the older stand especially with sloping topography and on drier sites (Troedsson & Utbult, 1972).

The intensity of nutrient liberation varies with the degree of mixing of the surface layers, eg. how large a proportion of the humus is mixed with mineral soil or torn loose and deposited on the surface. In both cases, the rate of mineralization of organically bound nutrients is faster than that of intact, undisturbed humus (Lundmark, 1985, cf. Berg & Staaf, 1983; Lundmark & Nömmik, 1984). Chemical analysis of typical mor humus layers buried under mineral soil indicates, at least in the first

year following site preparation, that the liberation of available nitrogen occurs at 2 to 3 times the rate in undisturbed mor humus. Mixing of humus and mineral soil increases the risk for leaching losses since the formation of mobile nitrate ions is favoured (Lundmark, 1985). Furthermore, there is a lag before vegetation becomes established or is able to take up large amounts of nitrogen.

Some Soil and Growth Experiments

The best known Swedish experiment on the long term effects of site preparation was established in 1934-1935 on a sandy heath in northern Sweden (Holmbäck & Mälmström, 1947). Burning, "spade inversion" (intensive treatment), clipping, and non-treatment were compared. Initial establishment showed the best growth with inversion but after 30 years trees with the inversion treatment showed reduced growth relative to non-treatment (ie. 20% lower volume at age 50). Only 22-28% of the original amount of total nitrogen remained in the spade inverted plots after 30 years. The results suggested that a large amount of nutrients were lost by leaching (Lundmark, 1977).

A similar experiment with spade inversion and "complete" disc trenching was established on a sandy heath in southern Sweden in 1977. Ammonium and nitrate levels were monitored for four years. The amount of ammonium increased steadily to 63 kg/ha in the untreated plots, with an insignificant accumulation of nitrate. The spade inverted plots showed high initial levels of ammonium and nitrate but by the fourth year there was only 18 kg/ha of ammonium and nitrate combined (a loss of 45 kg/ha N). It should be noted that the annual nitrogen requirement for a middle aged pine stand on that kind of site is about 20-30 kg/ha though a seedling stand would require about a tenth of that (Lundmark, 1985).

Lysimeter studies that measure the concentrations of leached nutrients in soil water have indicated fairly large losses from intensively prepared sites, as shown in Table 3.

The small concentrations found in the nearby stream suggests that nutrients have been lost by denitrification and evaporation (Rosén & Lundmark-Thelin, 1986; cf. Burschel et al., 1977).

Table 3. Calculated leaching losses of total Nitrogen (kg/ha/yr) one year following site preparation in central Sweden. (After Rosén & Lundmark-Thelin, 1986).

	No site preparation	Disc trenching	Ploughing	Stream
From humus layer	22	32	41	4
From mineral soil	8	13	29	

In northern Finland, Kubin (1987) monitored the concentrations of nutrients (NO^3-N, NH^4-N, P,K, Ca, Mg, Na, and Fe) in surface run-off water from plots with different site preparation treatments. While the chemical composition of the runoff water would depend on many additional factors, it was found that site preparation increased nutrient leaching. High levels of nitrate and ammonium were leached 2-3 years following site preparation with continued removal for about 5 years. Potassium losses may continue for a longer period. The leaching of other nutrients was not considered to be as serious as those for nitrogen.

Logging slash contains roughly 65% of the nitrogen reserves of the above ground mature stand. About 60% of this is found in the needles. Thus, the breakdown of needles releases nitrogen which would contribute to the site's nutrient capital and subsequent stand development. Conditions following clear cutting, such as high irradiation and drying of the humus surface create conditions for slow decomposition of residue. However, site preparation that buries slash provides favourable temperature,

moisture, and aeration conditions that would hasten the breakdown of organic material and release of nitrogen.

Studies using needle litter envelopes placed in different microsites on different site types in northern Sweden have been carried out by Johansson (1987; cf. Hunt, 1987). The effect on needle breakdown was the same regardless of site preparation method. However, the longer term capacity of the needle slash to deliver nutrients would be affected by the area disturbed by site preparation (eg. Table 2). A shown in Table 4, ploughing resulted in a reduction of about 50% of the needle nitrogen after four years while disc trenching and mounding reductions were about 40% and 30% respectively. The longer term effects of these reductions in the nitrogen reserves would depend on the site qualities and total nitrogen capital. On the medium and high productive sites, nitrogen in needle slash makes up about 1% and 9% respectively of the total nitrogen capital. On poor sites, about 20% of the total nitrogen is found in needle slash. Thus, the longer term site productivity of a poorer site could be impaired by harsh treatment (Johansson, 1987).

Considerations For The Long-term

Site preparation methods which disturb large proportions of area and rapidly mineralize organic matter can reduce nutrient reserves and could have negative consequences on stand productivity. The risk for decreased productivity would be greatest on impoverished or dry, coarse textured sites. On cold wet sites with thick (inactive) humus, intensive site preparation may be a soil amelioration measure, needed to improve the circulation of many of the advantages of harsh site preparation (eg. ploughing) but without the radical soil disruption and potential nutrient loss. Some recent results (Hunt, 1987) indicate that mounding may provide as good or better regeneration results than harsh methods on medium to good sites.

More research work should be carried out to examine the effects of harsh site preparation measures on site productivity

Table 4. Reduction in total nitrogen (%) in logging slash needles of Pinus contorta four years after harvest with four site preparation methods on three site types in north central Sweden. (After Johansson, 1987.)

Site type	Site index H100 (m)	Total N in needles at harvest (kg/ha)	Not site prepared	Mound	Disc trench	Plough
			Total N reduction (%)			
Poor sediment	14	30	0	27	40	60
Medium-good moraine	20	40	2	28	45	38
Very productive moraine	22	47	9	30	34	53

and stand development. This is difficult since such experiments are expensive and require large homogeneous areas.

Choice of treatment and short term regeneration results should also be considered in terms of potential effects on stand productivity.

It is desirable to make silvicultural treatments as site specific as possible.

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Comparison of Two Bräcke Scalp Profiles and Seeding Mechanisms for Direct Seeding Jack Pine in Northwestern Ontario

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Introduction

Canada's unique low opportunity cost for land and relatively slow growing tree species make low cost per hectare silvicultural investments a realistic strategy to maintain leadership in the world supply of wood fibre (Sedjo, 1986; Benson, 1988). Direct seeding of jack pine concurrent with Bräcke site preparation is one such low cost silvicultural method used in Northwestern Ontario (Smith, 1980).

The conventional Bräcke scarifier seeding configuration consists of a seeder with a brass slider plate dispensing seed onto scalps created with a 17 toothed reduction gear setting. This configuration was compared to a prototype plastic rotating seeder plate that metered seed into a stream of compressed air directed onto scalps formed by a 15 toothed reduction gear setting. The 15 toothed gear setting creates scalps that have a longer, shallower profile but results in fewer scalps per hectare than is produced by the 17 toothed gear setting.

The prototype seeder was found to be more reliable and damaged fewer seed than the conventional seeder in bench tests (Kolk, 1988). It was anticipated that the prototype seeder combined with a flatter more stable scalp produced by the 15 toothed gear setting would result in better seedling emergence and improved stocking had demonstrated the importance of a stabilized seed spot by reducing seed losses from scalp erosion. Results from tests that compared the new configuration to the conventional one are presented in this paper.

Methods

Two Bräcke four-row scarifiers were fitted as follows. One scarifier had four prototype seeders with alternating 15 toothed and 17 toothed gear settings for each machine frame row. The other scarifier had all 17 toothed gear settings with the conventional seeders. The purpose of the former configuration was to facilitate comparison of the different scalp profiles independent of seeder mechanism type.

Each Bräcke scarifier was randomly assigned one of twelve 40 metre long corridors to scarify on a sandy outwash plain 160 km northwest of Thunder Bay, Ontario. Site preparation was completed by each machine on May 15, 1988. Three months later, scalps in each corridor were scored as either stocked to jack pine or empty. A T-test and Chi-squared test (Steel and Torrie, 1980) was used to evaluate the differences in mean percent stocked scalps and total stocked scalp number respectively.

Results and Discussion

Figure 1 summarizes the results. The prototype seeder combined with the 15 toothed gear setting gave the best results with 45% stocked scalps. Although this difference was significant compared to the old seeder at the 17 toothed gearing (19%) a meaningfully paired T-test failed to detect differences between the 17 and 15 toothed geared machine frames on the Bräcke unit with the prototype seeders (29% and 45% respectively).

This lack of test sensitivity is related to the large variances (coefficients to variance larger than 30%) associated with the short corridor length, small replication number and the short time interval between sowing and evaluation. Seedlings were small at the time of assessment and many could have been overlooked. Corridor lengths and replication number should be doubled in future experiments involving machine seeding. This trial should also be evaluated again in the fall of 1989.

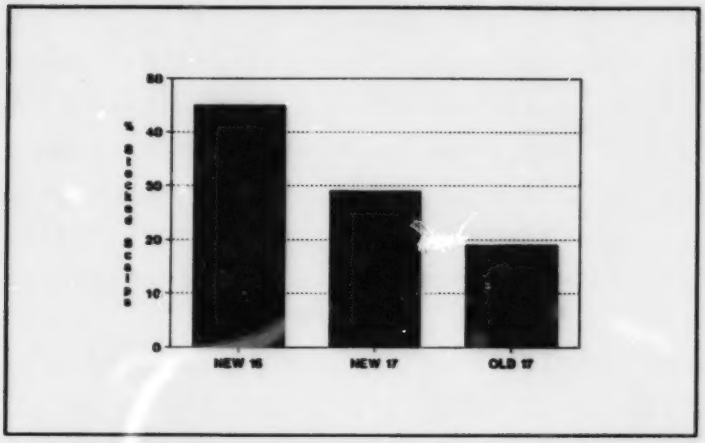

Figure 1. Histogram showing percent stocked scalps for:
i) NEW 15 = prototype seeder with 15 toothed gear setting,
ii) NEW 17 = prototype seeder with 17 toothed gear setting,
iii) OLD 17 = old seeder with 17 toothed gear setting.

The prototype seeder and 15 toothed gear setting also gave the largest number of stocked scalps in the test area (Table 1). Chi squared tests of pairwise comparison of seeder configurations were all highly significant.

Table 1. Distribution of stocked scalps.

	Stocked	Unstocked	Total
NEW 15	88	106	194
NEW 17	61	151	212
OLD 17	39	167	206

NEW 15 = prototype seeder with 15 toothed gear setting.
NEW 17 = prototype seeder with 17 toothed gear setting.
OLD 17 = old seeder with 17 toothed gear setting.

The results suggest that the prototype seeder and the 15 toothed gear setting will result in improved stocking over the conventional Bräcke seeder configuration, especially when these factors are combined. These results add further support to the

importance of seed spot microsite stabilization observed in earlier studies (Van Damme, 1988). Comparison of operational blocks treated with the 15 toothed and 17 toothed gear settings will be undertaken next fall.

Critical evaluation of the contribution made by the expensive compressed air component of the prototype seeder will be completed in the fall of 1989 before production begins on new seeders available to the market. Here, reliability of seed delivery in wet conditions as well as improved seedling emergence from more accurate seed placement with compressed air will be tested against the passive seed drop system.

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Pneumatic Seeder Trials
Fourth Year Results

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As part of the continuing refinement of Canadian Pacific Forest Products' powerhead scarifier, a pneumatic seeder was developed to allow simultaneous seeding of jack pine and black spruce. This report deals with the fourth year results from selected jack pine treatments only.

The purpose of the seeding trials was to determine the optimum combination of seeding rate and microsite placement, together with the influence of varying soil type on seeding success. Experimental design was a randomized split/split plot containing the following factors and factor levels:

Factor	Level	Assessment at 4th Year
Soil Type	Sand	X
	Sandy Loam	X
Seeding Rate	Control	X
	19,400	
	24,300	X
	32,400	
	48,600	X
Application Method	Pneumatic Seeder	X
	Hand Seeding	X
Microsite Placement (relative to furrow)		
	Edge	
	Bottom	X
	Slope	X
	Top	

Hand seeding was included in the trial as a standard against which to compare the performance of the pneumatic seeder. Treatments were replicated four times on each site.

Seed used in the pneumatic seeder was coated by Harris Moran Seeds Inc. of California. The coating process makes the seed much more uniform in shape, allowing for accurate singulation by the seeding device. The parallel test of hand seeded plots were sown with bare seed. Previous field trials by the company showed that the Moran coating does not compromise seed germination.

Performance was assessed on the basis of stocking, number of trees per stocked plot, and mean height of the tallest tree within each treatment plot. In addition, the microsite position of each seedling was also recorded. All measurements in both treatment and control plots, were conducted within the site prepared furrows on portions of the furrows containing suitably, prepared seedbed, at least in the furrow bottom. The reader is cautioned against direct extrapolation to operational seeding projects. Stocking is influenced strongly by the level of suitable seedbed and therefore, the results in an operational setting will be lower than those presented.

Trial results were evaluated by answering some simple questions.

Question 1

Which seeding rate gave the highest stocking?

Rate Seeds/ha	Furrow Stocking %
48,000	75.3
24,000	62.8

Since overall site occupancy is fundamental to good stand development, stocking is generally accepted as the most important assessment variable. However, as others have found, increasing the seeding rate does not result in proportional increases in stocking.

Question 2

Were the sites different in terms of their background stocking levels?

Site	Furrow Control Stocking %
Sand	35.8
Sandy loam	20.1

There were highly significant differences between sites associated with stocking from naturals, as evidenced by differences between the control plots. This difference is no doubt partly related to lower preharvest stocking levels on the sandy loam site, since the majority of plots on this site fell within a stand of barren and scattered jack pine.

In any event, the background stocking on both sides made a substantial contribution to overall stocking even on these full tree logged sites.

Question 3

For a rate of 48,000 seeds/ha applied with the pneumatic seeder, was the bottom seeding position better than the slope position?

Sandy Site

	Bottom	Slope
Furrow Stocking (%)	83.3	59.0
# Trees/Stocked Plot	3.1	2.3
Mean Ht. Tallest (m)	0.43	0.34

Sandy Loam Site

	Bottom	Slope
Furrow Stocking (%)	87.8	71.3
# Trees/Stocked Plot	2.8	2.6
Mean Ht. Tallest (m)	0.49	0.48

Statistically significant differences were detected for stocking and number of trees per stocked plot on the sandy site only. This could be a function of a more unstable slope microsite on sandy soils resulting in washing and/or burying of seed and germinants. A fairly large variance associated with stocking on

the slope position on the sandy loam site resulted in non significant differences between bottom and slope positions, even though the difference in mean stocking was relatively large.

Question 4

For the prescribed rate 48,000 seeds/ha applied by machine and directed at the furrow bottom, what were the stockings by microsite?

Furrow Microsite	Furrow Stocking %
Edge	14.9
Bottom	72.4
Slope	33.6
Top	3.3

The stocking figures, of course, reflect suitability of each microsite for germination as well as the accuracy of the seeder in placing seed in the prescribed microsite. However, it is clear that the bulk of the stocking was found in the prescribed microsite.

Question 5

After four growing seasons, were there growth differences between microsites?

	Mean Height (m)	
Microsite	Sand	Sandy Loam
Edge	0.37	0.48
Bottom	0.38	0.42
Slope	0.37	0.44
Top	0.38	0.44

Within sites, no significant differences were detected amongst the four microsites, however, a highly significant difference was detected between the two sites with the finer textured sandy loam showing a definite overall growth advantage.

Question 6

For the furrow bottom seeding position at 48,000 seeds/ha, was machine stocking as good as the hand seeding control?

		Sand	Sandy Loam
Furrow Stocking (%)	Machine	83.3	87.8
	Hand	92.5	97.0
Trees/Stocked Plot	Machine	3.1	2.8
	Hand	4.0	3.5
Mean Ht. Tallest Tree (m)			
	Machine	0.43	0.49
	Hand	0.48	0.44

Significant differences were observed on the sandy site for stocking and number of trees per stocked plot, however, from a practical standpoint, the figures for machine seeding must be considered quite acceptable.

Refinements to the powerhead scarifier and pneumatic seeder unit are continuing. For example, the digging effort of the scarifying heads was reduced, which in turn has all but eliminated the slope and top microsites within the furrow. As well, longer and more durable hoses, through which the seed flows, were attached to the scarifier arms to allow more accurate placement of seed within the furrows.

The company currently operates two powerhead scarifiers equipped with pneumatic seeders, site preparing and seeding jack pine on 800 to 1,000 hectares of cutover during May and June each year. The current prescription, based on the results of the field trials calls for a seeding rate of 48,000 seeds/ha applied in the furrow bottom.

Gaspardo Seeding Unit for Disc Trenchers

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The text of the report is contained in:
Equipment Assessment Committee, Forest Resources Group.
Report No. 22. Sault Ste. Marie, Ontario.

Synopsis

The Gaspardo seeding unit as adapted for installation on disc trenchers was field tested in Dryden District of the Ontario Ministry of Natural Resources. Although the final testing prototype of the unit appeared to be successful, it should undergo further testing to ensure that no unforeseen difficulties arise.

Testing showed that the seeding unit is easily calibrated to deliver seed at rates varying from 200 seeds per 30 cm to 1 seed every 60 cm. Once set, the delivery rate appeared not to vary. The final prototype was tested over 20 hectares of seeding at the rate of 1 seed per 25 cm without problem. The test was terminated due to a lack of seed and freezing temperatures.

It was concluded that since the unit was attached to the skidder for a full three weeks of scarification (not always operating) and did not deteriorate structurally, it is sturdy and will withstand the rigors of the site preparation process.

The advantages of the seeding unit and its application are directly related to the use and advantages of disc trenchers, with the added benefit of a one step regeneration process. The seeder unit could be attached easily to any of the currently available trenchers with minimal modifications.

A number of recommendations for improving the seeding unit were made including:

1. The seed delivery tubes should be relocated to the bottom of the casing. This will correct the kinking of the tubes when debris falls on them.

2. The unit should be equipped with a hydraulic flow control valve. The original design does not have one. The unit requires only 300 psi. and was hooked up directly to the skidder's hydraulic system at 2500-3000 psi. This resulted in excessive heating.
3. The unit should be modified so that the front can be opened and inspected without taking off the top. The hinges should be strengthened.
4. The unit is both hydraulically and electrically operated. Modifications should be made so that it is electrically operated only. This would make the unit simpler and eliminate the need for the flow control valve for the vacuum pressure.
5. The control panel should be modified so that it is smaller and mounted on the control panel of the skidder.
6. Further testing and modifications should be done on the positioning of the hose brackets at the back of the trencher frame. An adjustable set-up is desirable so that the seed may be directed to the bottom, side or top of the trench.

Site Preparation for Sawlogs

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With the initiation of Forest Management Agreements (FMA), the companies have assumed responsibility for regenerating the areas covered by these agreements. The Buchanan Group of Companies presently hold two FMA's that generate a large portion of the sawlog requirement in north central and northwestern Ontario. It is the intent of the Buchanan Group of Companies to maximize the sawlog production on each of its FMA's through the application of a range of silvicultural techniques.

These techniques will include the promotion of rapidly growing species such as jack pine on suitable sites; controlling the physical growing situation for spacing, density, and competition; and eventually using genetically improved seed to improve growth and yield.

A key component of any silvicultural program is the preparation of the site for either planting or seeding. This process of site preparation is similar in nature for both sawlog and pulpwood production. The requirement for suitable planting spots or seedbed are exactly the same, however, with sawlog production microsites must be at a wider spacing (minimum 7 feet x 7 feet).

This combination of wider spacing, controlled growing situation, rapidly growing species and genetically improved seed will increase growth and yield while reducing the rotation age. This, of course, means the increase in both quality and quantity of sawlogs with a substantially lower carrying period (less than 70 years).

Given the wider spacing and larger investment on the more productive sites, the protection of all crop trees from losses to nature is extremely important. Any significant loss will result

in openings in the canopy and a subsequent reduction in growth and yield.

The following sections have been divided into the objectives and strategies employed by the Buchanan Group of Companies in the site preparation program to produce quality sawlogs as rapidly as possible.

Site preparation objectives

When developing the site preparation program on an FMA dedicated to sawlog production, there are a number of key objectives and criteria that must be considered. Obviously, the combination of site, stock, and species play a key role in the development of any site preparation program. The availability of suitable stock by species and the sites to plant it on, heavily influences the program.

There are four overall objectives that provide guidance for the site preparation program being applied to the FMA's held by the Buchanan Group. These can be summarized as follows:

1. Where the site will be regenerated by planting bareroot or container stock, the site preparation technique must produce high quality, uniform planting spots at 7 feet by 7 feet intervals.
2. Where the site will be regenerated by direct seeding, the site preparation technique must produce microsites that will allow germination and survival of seedlings. It is recognized that direct seeding gives limited control over stocking or density, and therefore, attempting to control these parameters at the site preparation stage is questionable.
3. The removal or alignment of slash is an important component of the site preparation program, particularly where a highly productive site and tree planting are involved. These site types tend to produce extremely heavy slash which impairs planting and results in limited spacing and density control.

4. The site preparation program must either suppress or eliminate all competing vegetation. This vegetation can decrease growth and yield and create mortality by suppressing the crop trees. Given the wider spacing, any loss of crop trees creates a subsequent loss in both growth and yield.

By applying these four guiding principles when developing the site preparation program, it is felt that a substantial gain in growth, yield, and quality will be achieved.

The following strategies are being applied to the site preparation program to ensure that each of the previous objectives is achieved.

Site preparation strategies

There are six basic site preparation strategies that give direction to the program. These strategies are listed and described in the following six subsections.

1. Conversion to wider spacing (7 feet x 7 feet).

Historically, site preparation equipment has been designed to produce planting and seeding microsites at 6 feet by 6 feet spacing. This tends to produce fully stocked stands at an early age, however, the diameters are generally less than plantations with wider spacings. This wider spacing must be applied with some caution as height growth and plantation survival can be adversely affected by increasing the spacing.

This increase to 7 feet by 7 feet spacing is felt to be an intermediate step and is reasonably conservative with respect to sawlog production. This strategy has a number of initial problems in that the site preparation equipment has to be converted to produce quality microsite with a wider spacing. This generally means producing new components such as longer drawbars and wider machine frames. In some instances, it is impossible to convert a piece of site pre-

paration equipment without completely reconstructing it. This tends to limit the options available to the company when selecting site preparation equipment.

2. Ensure site preparation is suitable for both planting and seeding.

When prescribing and applying a site preparation technique to a site, the intent is to produce high quality microsites that can be either planted or seeded. This is, of course, dependent on the site type with a range of sites being ideally suited to both seeding and planting.

By applying this strategy to those sites that are suitable, the company will increase the regeneration options available, and any changes in seed or stock will have less of an impact on the regeneration program. An equally important feature of this strategy is the ability of these sites to be carried an additional season should stock or seed not be available.

It is recognized that this strategy is generally restricted to the sandier site types.

3. Combine site preparation techniques.

This combining of site preparation techniques generally occurs on the highly productive sites where a single operation will not produce acceptable results. The combinations available include prescribed burns, mechanical equipment, and chemical applications. It is recognized that multiple treatments increase the cost; however, these costs can be reduced by applying the methods simultaneously (e.g. Bräcke herbicider). It must also be recognized that the sites requiring these treatment methods are highly productive and produce the highest volume and quality of sawlog material.

Unfortunately, there are presently very few pieces of equipment that are adapted for simultaneous chemical appli-

cations and given the nature of prescribed burns, they cannot be applied at the same time as other operations. When applying these combined techniques, it is important that all of the operations occur in the same year, as this reduces operating costs (road maintenance, supervision) and brings the plantation to free-to-grow status earlier.

4. Eliminate competing vegetation.

This strategy is extremely important given the sawlog requirement and the wider spacing. Any mortality or loss in growth in a plantation will result in openings in the canopy and subsequent lower yields of sawlog material. If the losses are significant enough, the plantation may not achieve crown closure and sawlog production will be severely limited.

With the emphasis being placed on fast growing species (jack pine), wider spacing, and genetically improved stock, the question arises as to the requirement for "grooming" species during the developmental stages in a plantation. The feeling is that this is not a requirement at intermediate spacings of 7 feet by 7 feet.

5. Equipment and site compatibility.

When mechanically treating a site, the type of prime mover and site preparation equipment must be matched to the site and physical situation. This generally means heavier equipment as the site types increase in productivity. Unfortunately, this also tends to produce higher costs as heavier equipment is more expensive to operate and is less mobile.

The general trend in the Buchanan Group of Companies is to use highly mobile operations wherever possible. This usually means rubber-tired skidders with Bräcke scarifiers, disc trenchers, or light drags. It is recognized that not

all sites can be suitably treated with lighter equipment and there is a place for tracked equipment within the silvicultural program.

This direction towards skidders is driven by the need to be cost effective while still delivering quality site preparation. It is recognized that rougher sites can be operated with skidders while lost time is reduced and repair costs are considerably lower.

6. Prioritization of operations.

The areas being scheduled for site preparation operations must be priorized based on specific criteria. The criteria used by the company reflects the need to produce plantations that contain a high proportion of sawlogs within a reasonable distance from the mill.

The four specific criteria that provide the greatest influence on the site preparation program are location, productivity, area size, and access. These criteria are relatively straight forward in that preference is given to large, highly productive areas that are close to the mill and have long-term, all weather access.

This does not mean less desirable sites will not be treated, but it does give firm direction on the order with which these areas will be scheduled for treatment.

The Buchanan Group of Companies is committed to producing a cost effective silvicultural program that relies on genetically improved stock, wider spacing, faster growing species, and protecting plantations from losses to nature.

Site Preparation Research at FERIC

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Introduction

The following is a brief description of the Forest Engineering Research Institute of Canada (FERIC) and the research program in site preparation of the Eastern Division.

What is FERIC?

FERIC is a non-profit research and development organization funded jointly through a partnership of the forest industry, the Government of Canada and the provinces. The Institute was formed in 1975 to conduct research and development aimed at improving the efficiency of woodlands operations relating to the harvesting and transportation of wood. The mandate has since been expanded to include silvicultural operations and woodlot technology in 1981 and 1985 respectively.

Membership in FERIC is voluntary, and the current industrial members utilize more than 60% of the total Canadian wood harvest. The Ontario Ministry of Natural Resources is a provincial member, participating in the silvicultural operations and woodlot technology programs.

FERIC is comprised of a Head Office and two divisions. The Eastern Division, situated in Point Claire, Québec covers the territory from Saskatchewan to Newfoundland. The Head Office is also located in Pointe Claire and the Western Division is in Vancouver.

In the Silvicultural Operations Group, there are four researchers and one forest technician. Research priorities and projects are set with the guidance of the Advisory Committee for Silviculture Engineering Research. The Committee is comprised of

representatives from the industry, provinces, the Canadian Forestry Service, universities, and the Canadian Pulp and Paper Association.

The work effort of the group over the past few years has been concentrated into the following six main areas: site preparation; prime movers; regeneration techniques; precommercial thinning; and the harvesting/silvicultural interface.

The purpose of this presentation is to provide an overview of the research activities in the field of site preparation. Projects concerning prime movers are included because the prime mover plays an important role in site preparation operations.

Site Preparation Research Program

1. Evaluation of Site Preparation Equipment

To date, FERIC has evaluated over 15 pieces of site preparation equipment. They range from motor-manual tools, to one-, two- and three-row scarifiers, and from passive, mechanical units to the more recently developed powered scarifiers. A number of these studies have been done in cooperation with other agencies such as the Great Lakes Forestry Centre and provincial governments.

FERIC does three basic types of evaluations: engineering assessments, short-term studies, and long-term evaluations. Engineering assessments are usually performed on prototypes or machines that require modifications to address certain weakpoints in design. Some recent examples include modifications to the Le Crabe disc harrow, and design assistance to the developer of the La Taupe scarifier.

FERIC's machine evaluations are designed to assist future users in appraising the current status and prospective value of specific equipment. Short-term studies describe potential productivity under measured, but limited, operating and site conditions. Technical and operating characteristics are also under study. A short-term evaluation is comprised of a pre-treatment assessment (similar to and adapted from a method developed by the

Great Lakes Forestry Centre), a time and motion study, and a post-treatment assessment. Since biological studies are outside of FERIC's mandate, the effectiveness of a treatment is measured against the prescription provided by the cooperating agency.

Long-term studies provide information on longer-term productivity, mechanical availability, and causes of downtime. Study duration is at least one site preparation season. The Silva-Wadell scarifier is a recently introduced machine that was the subject of both short-term and long-term studies by FERIC in Québec and Manitoba. A report is to be published in early 1989.

2. Treatment of Difficult Sites

This project is aimed at site preparation techniques that can be used for the treatment of backlog and "not sufficiently regenerated" areas, stand conversion and the rehabilitation of insect or disease-killed stands. The use of conventional site preparation equipment is restricted by heavy residuals and brush conditions. There have been three separate studies under this project to date:

i) crushing or trampling operations where the objective is to simply push the residual stand to the ground for prescribed burning. Information on these operations is lacking; FERIC is investigating the effectiveness of various sizes of tracked and wheeled prime movers and downing chain for this work.

ii) motor-manual scarification tools. FERIC made evaluations of the La Taupe scarifier in understorey scarification for stand conversion, and in scarification on small, scattered, steep-sloped areas. A report on these studies is due by the end of the year.
Performance tests on four other brush saw mounted scarifiers were done in 1988. The tools were evaluated in terms of productivity and the ability to retain a

Figure 1. The Silva-Wadell mounted on a John Deere 640 with auxiliary engine.

mixed soil in the microsite. A technical note on these trials will be available in early 1989.

Figure 2. Trials of the La Taupe motor-manual scarifier.

iii) brush cutting equipment. A review of brush cutters for site preparation was initiated in 1988. The equipment includes integral machines (eg. Hydro-Ax 720) and attachments, such as boom-mounted flails, saw-type heads, and front-mounted, horizontal-shaft cutters. A report on the review and production studies will be made in 1989.

Evaluation of the Franklin 595 Site Preparation Skidder

The skidder, built specifically for site preparation work in the United States, was introduced to Canada in 1988. The machine

features a 10-speed mechanical transmission and has a power rating of 157 kilowatts.

Seven Franklin 595 skidders were monitored in a long-term study on four site preparation operations in Ontario during the 1988 scarification season. Implements used include the Bräcke four-row, TTS-Delta, Donaren 180D, Percheron H2M, and barrel and chains. Data has also been received on a unit pulling six rows of anchor chain on a 7.3 metre drawbar in Saskatchewan operated by Woodlands Enterprises Ltd. A report is in preparation and is to be published in 1989.

Figure 3. The Franklin 595 Site Preparation skidder, pulling a Donaren 180D powered disc trencher, near Dryden.

4. Tire Applications in Silvicultural Operations

a) Tire Wear

Tire wear measurements are presently being taken on approximately 50 skidders used exclusively in site preparation operations. Early results indicate a wide range of tire wear rates and the importance of chains for tire protection. The project will continue into 1989 to get enough hours on the tires to permit final analysis.

b) Wide Tires

A joint study between FERIC and the Ministère de l'Énergie et des Ressources du Québec was initiated in the spring of 1988

to determine the life of wide, high-floatation tires on scarification operations in the Abitibi-Témiscamingue Region.

Firestone 73x44-32 tires with double-diamond Québec traction chains were installed on a John Deere 640D pulling a Silva-Wadell scarifier. A similar machine with 30.5 inch tires was operating in the same areas. The contractor operating both skidders prefers the wide tire equipped skidder, using it in the softer blocks, and to free the other when stuck.

To date, there are approximately 1500 hours on the tires with no signs of premature wear or damage. Since the prime objective of the study is to investigate the tire life, the cooperative study will continue in 1989.

Figure 4. Ongoing wide tire trials in Abitibi-Témiscamingue Region, Québec.

5. Drawbar Pull Requirements of Silvicultural Implements

The calculation of the drawbar pull requirements of silvicultural implements is an important step for proper matching of prime mover to implement, in the design or modification of prime movers for silvicultural work, and in the design of the implements themselves.

In 1988, FERIC conducted a series of tests to measure the drawbar pull requirements of common rear-mounted implements that use a hitch or mainline system. To date, the Bräcke hydraulic three-row scarifier, the La Crabe disc harrow, and the TTS-35 disc trencher have been investigated in New Brunswick and Québec.

Additional studies in Ontario of the Bräcke three-row and four-row scarifiers, and barrels and chains were also conducted in the fall.

The study methodology in the field includes the following steps:

1. selection and assessment of test strips;
2. instrumentation installed on the prime mover, which includes hitch mechanism with 222-kN load cell; Cambell CR-10 data logger; remote control radio and antenna; and program running light;
3. operating the instrumented prime mover in test strips with a time study and taking a video to calculate slip on the wheels;
4. download data to a portable computer at roadside. Data is then checked and dumped onto a disk.

Methods of measuring front-mounted and direct-mounted implements will be investigated, and it is hoped to encompass such implements within the continued program next year. Information dissemination will be in the form of short technical notes for each implement studied.

Figure 5. Field tests to measure the drawbar pull requirements of silvicultural implements.

6. Ideal Prime Mover Powered Scarifiers

FERIC has been involved with powered disc trenchers since their introduction in 1981. One of the common recurring problems is the lack of compatibility of North American skidders to this application, caused primarily by the need to supply constant hydraulic power at a relatively slow travel speed. A number of members and contractors have concerns about the limited choice of carriers, and their high operating costs.

The requirements of a prime mover for powered site preparation are being defined under this project (drivetrain, engine and hydraulic power, tractive effort, etc.). Problems with off-the-shelf equipment are also being identified. A report outlining the desirable characteristics of an ideal machine, and potential modifications to existing ones will be prepared. The findings will be discussed with prime manufacturers.

Figure 6. Downpressure and rotation speed measurements were taken under the ideal prime mover project.

Summary

Research into new site preparation techniques and the prime movers used in the silvicultural practice has been a priority work area since the inception of the silviculture program. As long as stand establishment remains an important issue for our industrial and provincial members, FERIC will be actively involved site preparation research and development.

Site Preparation Prescriptions Should be Based on the Silvics of Our Crop Species

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" Behold a sower went forth to sow;
And when he sowed...

Some fell upon stony places whereon they had not much earth...
And when the sun was up they were scorched;
And because they had no root they withered away.

And some fell among thorns;
And the thorns sprung up and choked them;
But others fell into good ground and brought forth fruit...

Who hath ears to hear, let him hear."

Abstract

Site preparation prescriptions should be based upon proper knowledge of the factors affecting seedling survival and growth. Critical to the decision-making process is some knowledge of the silvics of the desired species including requirements for germination, survival and root system growth. Soil and air temperature, quantity and quality of light, soil nutrients, soil texture and structure, available soil moisture and aeration, and the presence of competing vegetation can all be modified by site preparation to create a favourable micro-site condition. Site preparation prescriptions should be site specific to account for the wide variation in post-harvest site conditions commonly encountered in the boreal forest. In the absence of specific data defining "optimal micro-site conditions" for either black spruce or jack pine, field staff must set site preparation objectives using an adaptive management approach which integrates their knowledge of the local site conditions, conditions under which

previous regeneration was successfully achieved, equipment capability and last, but not least, species' silvics.

Key Words

boreal, black spruce, jack pine, Picea mariana (Mill.) B.S.P., Pinus banksiana Lamb., silvics, site preparation

Introduction

For some 2000 years, man has wrestled with the challenge of establishing crops on a range of site conditions. Even the farmers of biblical times recognized that some site conditions were more favourable for establishing and growing crops than others. Exposure, depth of mineral soil, presence of organic material, moisture status, stoniness and the presence of competing vegetation were a few factors which affected seedling performance (survival and growth).

Logging in the boreal forest often results in changes to the physical and chemical features of the rooting zone and to the micro-climatic conditions near the forest floor. These will influence seedling regeneration and subsequent forest development. The most significant and immediate changes include shifts in the soil structure and rooting depth, soil temperature, air temperature, intensity and quality of light reaching the seedling, amount and condition of the organic litter layer (duff), soil moisture availability, and availability of soil nutrients (Kramer and Kozlowski 1979; Gates 1980; McMinn 1980). Of the many plant processes that are influenced by temperature, light, and moisture, seedling establishment is one of the most crucial in the early life of a forest stand.

The primary objective of forest site preparation following harvest should be correction of site factors unfavourable to seedling survival and growth. Unfortunately, physical site limitations, the presence and abundance of residual standing timber, advance growth, and the need to produce a percent of

exposed mineral soil have unduly influenced the development of the site preparation prescription - often at the expense of the biological needs of the seedling.

The purpose of this paper is to discuss the relationships which exist between the silvics of two principal boreal tree species in Northwestern Ontario - jack pine (Pinus banksiana Lamb.) and black spruce (Picea mariana (Mill.) B.S.P.), and the development of site preparation objectives. The general factors of site which may be modified by site preparation to improve seedling establishment and performance will be reviewed. Specific environmental needs of jack pine and black spruce for germination, establishment and growth will also be considered.

Site Factors Can Influence Crop Establishment and Growth

Silvics - "a knowledge of the nature of forests and forest trees, how they grow and reproduce and respond to changes in their environment".

Site preparation - "a disturbance of the forest floor to create optimal conditions for natural regeneration, seeding or planting".

The development of site preparation prescriptions based upon the silvics and biology of the species is not easy - nor would one expect it to be! Firstly, the conditions for tree survival are not necessarily the same as those which influence the growth of the species being regenerated. Secondly, the post-harvest conditions which may be modified with site preparation to favour survival and growth are seldom uniform across boreal sites. Finally, site preparation is usually prescribed to achieve a number of objectives; the creation of biologically-optimum micro-sites may or may not be emphasized (Table 1).

Micro-site conditions to be achieved by site preparation should be defined in terms of the factors which are directly available to the plants for growth (Figure 1). Light, heat, water, chemical, and mechanical factors all affect establishment

and growth. These micro-site conditions are a sub-set of the well known site factors of landform, soils, climate and vegetation; in other words, the ecosystem. Site preparation acts to create an environment under which certain physiological processes such as transpiration, moisture uptake, nutrient uptake, translocation of moisture and nutrients, photosynthesis, and metabolism are enhanced or suppressed. These same processes act singly or in concert to either enhance or limit germination and root and shoot growth of the developing seedling. Little information is currently available to help define those micro-sites which are "optimal" for the growth of black spruce or jack pine on specific sites in Northwestern Ontario. However, information on site features related to seedling growth and which can be influenced by site preparation can be used to deduce some characteristics of what an "optimum" micro-site may be.

Table 1. Objectives for site preparation.

a. Reduction and removal of vegetation that competes with regenerating forests for light, moisture and soil nutrients;

b. Creation of biologically-optimum micro-sites for the survival and growth of the seeded or planted trees;

c. Reduction or removal or alignment of slash in order to allow access to the site for subsequent silvicultural treatments; and,

d. Control of the spacing and stocking of seedlings in the regenerating forest.

Soil Temperature - Low Soil Temperature

Root development is a major factor controlling survival and first year growth of planted trees. On many sites in northern Ontario, root growth is restricted by either cold temperatures, mechanical impedance, or poor aeration during wet periods (Morris

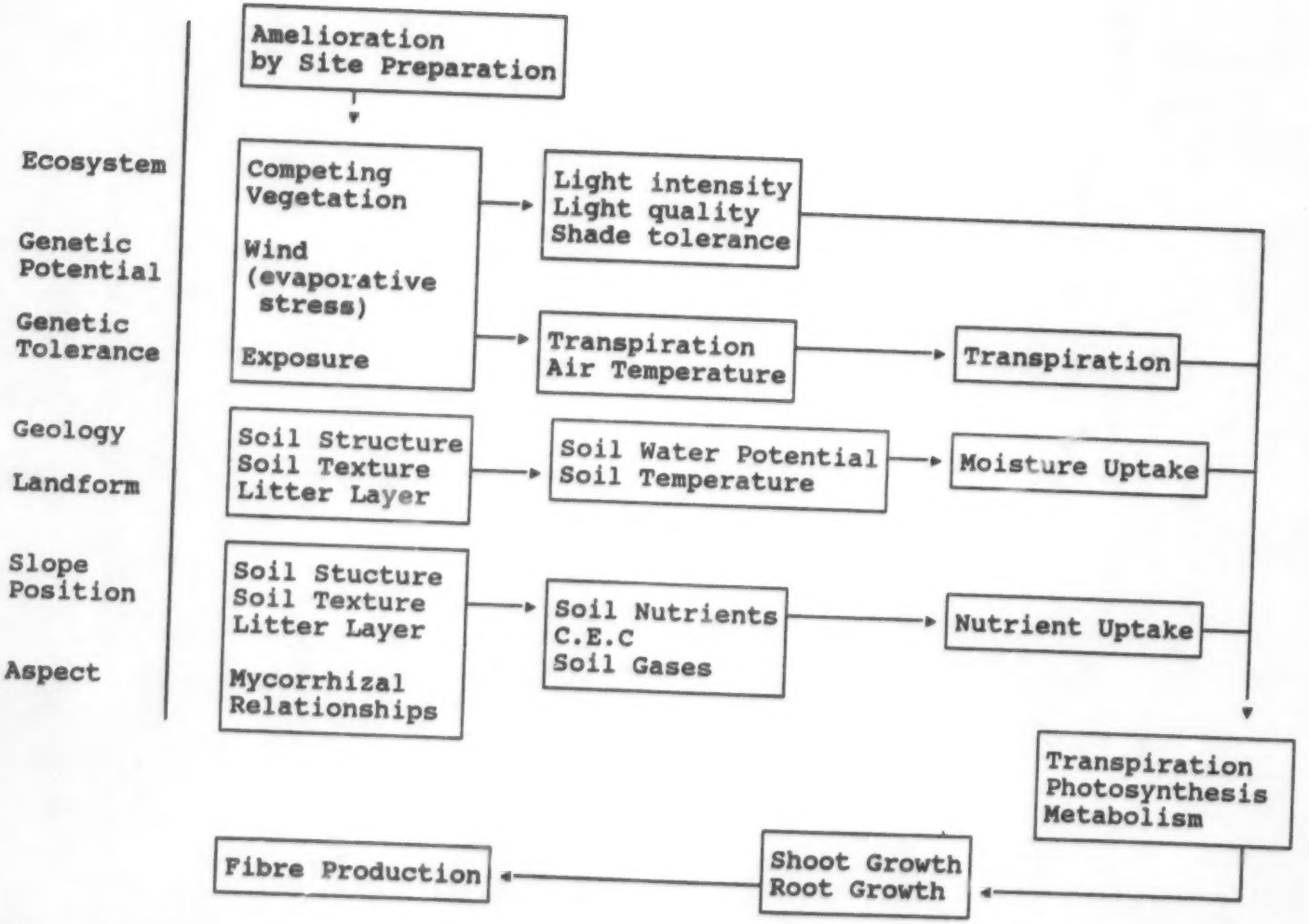

Figure 1. Components of a micro-site include those features of the ecosystem which influence survival and growth.

1988). Soil temperatures in undisturbed northern coniferous soils are often below the minimum of 5·C. for seedling root growth during much of the growing season. The underlying mineral soil may not thaw until July 1 annually and average soil temperatures of 12· to 17· C are usual. Temperatures of peaty-phase and organic soils seldom rise above 12· C. Below optimum temperatures are still common even though harvesting may have removed the overstory and allowed warming of the upper organic layers (Dobbs and McMinn 1973, 1977). The organic horizons often act as an insulating blanket to the mineral soil beneath.

Conifer seedlings planted into colder soils will often experience moisture stress and desiccation due to lack of a well developed root system. Plant moisture stress can be extreme even if there is adequate moisture around the roots, or if soil aeration is poor, or if soil temperatures are low. This is particularly true for soils with a high silt/clay content or those soils with a continuously high water table. Low temperatures depress water uptake by the roots because metabolic activity of the roots is lowered and the viscosity of the available water is greater at cold temperatures (Kramer 1959; Camp 1963).

When the stand is opened up and the surface organic layers are either removed or mixed in with the mineral soil, temperature levels increase. This action results in increased root regeneration, and acceleration of decomposition of the organic matter by microbes or pyrolysis which in turn releases nutrients (particularly nitrogen) tied up in undecayed organic material (Jurgensen et al. 1979). Exposed mineral soils will retain the heat and will have average rooting zone temperatures of 20· to 25· C depending upon the degree of exposure. Removal of the surface organic layer on colder fine-textured soils to increase the soil temperature may be counter-productive if the site is prone to high water tables or periodic flooding and lack of adequate aeration. Likewise, the benefit of removing the organic layers on sandy and coarse loamy soils to increase soil temperature may be negated by

creating a droughty, nutrient impoverished micro-site. Under such conditions, mixing of the mineral and organic material provides the best micro-site.

High Soil Temperature

Optimum temperatures for seedling root growth are sufficiently high (Heninger and White 1974) and temperature decrease with increasing soil depth sufficiently great (Dobbs and McMinn 1973) for high soil temperature to be an improbable direct cause of poor seedling survival and growth. High temperatures on the surface of the ground, however, will influence germination of seed and damage the root collar of planted seedlings (McMinn 1980). Dark coloured surfaces (eg. surface organic layers) are prone to excessive soil temperatures and are not efficient at transferring the heat to the mineral soil horizons below. Temperatures in excess of 30° to 40° C are common at the air-soil interface in boreal cutovers. Prolonged exposure to these temperatures can result in desiccation and mortality of a conifer germinant or seedling. High heat loads created by opening up the forest floor can also cause drying of the surface through increased evaporation. As the surface dries, maximum temperatures will increase (Cochran 1969).

Exposure of lighter-coloured mineral soils by site preparation may reduce the likelihood of heat injury to seedlings at the air-soil interface and will reduce surface temperature variation during a 24-hour period (Hungerford and Babbitt 1987). Shading vegetation may also reduce the surface soil temperatures and evaporation of the available soil moisture. Allowing some vegetation (provided that moisture is not limited) to remain after site preparation will help reduce temperature extremes on the site. On sites where soil moisture is limiting or where the site is rapidly drained due to excessive stoniness or coarse textured mineral soil, mixing the organic layers with the upper mineral soil will help retard evaporation. However, this process will also result in increased surface temperatures.

Air Temperature

Vegetation on a cutover may reduce the air temperature sufficiently to reduce the seedling photosynthetic rates. Removal of shading vegetation by site preparation may, therefore, increase air as well as soil temperatures. In hot, dry locales, high air temperature may impair photosynthesis by affecting transpiration through the availability of moisture (Hobbs et al. 1980). Under these situations some vegetative cover may be permissable if the species are not heavy soil moisture users.

Soil Nutrients

Protection or enhancement of the forest soil's organic mantle via site preparation, provides a major tool for impacting the growth of forested ecosystems. Roots can only absorb and use nutrients that impinge on the surface of the roots. The flow of water through the soil, or the interception of water by root growth, brings nutrients into contact with the roots. Since much of the nutrient capital on a site supporting a mature forest is bound up in the organic horizon and living plant biomass, site preparation can be used to incorporate a portion of this organic material into the mineral soil. Decaying wood and on-site residues are particularly important as sources for nitrogen input and storage (Morris 1988). This material usually has substantial moisture holding capacity and cation exchange capacity and supports most of the nitrogen fixing activities and important symbiotic ectomycorrhizae that directly contributes to tree growth potential. It is important that the conifer seedling roots have access to the nutrients released from the decomposition of the organic material.

Excessive site preparation which removes or makes the organic matter inaccessible to the growing seedling may result in large removals of nitrogen and a significant loss in organic matter-derived cation exchange capacity. Changing the amount of organic matter on a site may also favour pioneer non-crop vegeta-

tion better adapted to a low organic matter content soil. On many soils, removal of surface layers to expose mineral soil may leave seedlings without access to an adequate supply of nitrogen (McMinn 1980). Use of site preparation techniques that retain surface organic material accessible to seedling roots may enhance seedling growth. Inverted mounds or ridges of inverted surface organic material covered by mineral soils (eg. such as that created by the Bräcke, TTS, Young's teeth, and drags) are likely to be the most beneficial. The exposed mineral soil will increase soil temperature and will be useful in controlling non-crop vegetation.

Soil Moisture and Aeration

On sites with a high water table or subject to periodic inundation, site preparation which removes surface layers may commonly create waterlogged micro-sites in which nothing can grow. Root development can be restricted at aeration porosities below 10 percent (Morris 1988). Soils without adequate aeration and drainage inhibit germination and root growth and nutrient uptake because these processes require oxygen (Kramer and Kozlowski 1979). Consquently, site treatments which produce raised planting spots such as mounds, scalps, and berms from furrowing are advantageous on these wet sites.

In contrast, on dry, well-drained sites available moisture may be limiting. Organic material by itself possesses a poor moisture retention capability and is rapidly drained. This material also provides poor capillarity for water movement to the root surface. Sunken micro-sites, scalped free of competing vegetation, such as those formed by patch scarifiers or disc trenchers, may accumulate moisture during rains which can be used by the crop tree (Shulz 1973, Haines and Pritchett 1965). However on moist sites where non-crop vegetation may be a problem, the raised patches and berms may not provide adequate competition

control and, indeed, often serve as ideal micro-sites for the competing pioneer species.

Site preparation may also be used to increase the infiltration, percolation, and retention of moisture on finer-textured soils by incorporating surface organic material into the upper mineral soil profile. Mixing or burying organic matter on sandy to coarse loamy soils is easily accomplished, whereas mixing on finer-textured soils is the only alternative for increasing the moisture retention capacity of these soils. Good soil aeration reduces the heat loss from the mineral soil and will result in a more even soil temperature throughout the day and growing season. Natural processes such as freeze-thaw and the activities of micro-organisms act very slowly to improve the moisture retention capacity of silts and clays.

Soil Structure

Compact, fine-textured, subsurface mineral soils are not readily penetrated by seedling roots. Removal of the organic layer and uppermost mineral soils with a high organic matter content, is likely to mean that seedlings are planted in an environment where root growth is inhibited (Minore et al. 1969). Seedlings may also be frost-heaved in exposed, fine-textured mineral soils.

Site preparation to mix mineral soil and organic matter can be employed to modify the rootability of the surface soil by decreasing resistance to penetration and increasing water and air transport through an increase in the volume of large pores. This will result in a reduced time for seedling lateral roots to interpenetrate and achieve full site utilization. Decreased bulk densities and increased rooting activity contribute to an increase in soil-root contact and the volume of soil from which nutrients and moisture can be extracted by the growing seedling.

Knowing How Black Spruce and Jack Pine Rooting is Key to Defining a Good Micro-site

The competitive ability of any individual germinant or seedling and the success of the species depends to a large extent on the size, shape, type, and efficiency of the root system. The type of structure and development of a species' root system helps us to understand the ecological requirements of a forest tree species, which in turn is necessary for deciding on the silvicultural action needed to regenerate the species (Table 2).

Since the final configuration of a root system becomes established quite early, site preparation should seek to enhance the "rootability" of soil and minimize those features which could interfere with root system development (e.g. compacted or rutted mineral soil, elevated water tables, presence of root restricting layers, moisture and nutrient deficiencies).

What Else Do We Know About Micro-site Requirements for Black Spruce and Jack Pine?

Both jack pine and black spruce possess different micro-site requirements with respect to light intensity, shading, temperature, degree of mineral soil exposure, soil moisture, soil texture and the presence of competing vegetation (Table 3). Site preparation prescriptions should be developed upon the knowledge of those features of the site which are limiting for the establishment and growth of the species, as identified in Table 3. The prescription should seek to optimize as many of the micro-site requirements as is possible.

Jack pine seed can survive and germinate when buried with up to 3 cm of mineral soil. Rapid establishment of broom moss (Dicranum spp) and haircap mosses (Polytrichium spp) will provide a moisture retentive micro-site highly suitable for germination. Usually, the micro-site condition should provide for a prolonged availability of competition-free mineral soil/organic matter mix, since seed germination will continue over a 3 to 5 year period.

Table 2. Rooting characteristics of jack pine and black spruce.

	Vertical distribution	Horizontal distribution
a.Jack pine		
	-tap root and lateral sinkers	-bulk of roots confined to upper 45 cm soil
	-avg. 40 cm by year 2	-avg. 1.2 m by year 2
	-avg. 55 cm by year 7	-avg. 4.5 m by year 7
	-roots may eventually reach depth of 2.7 m	-maximum distribution of 8.5 m
	-up to 15,220 kg/ha of fine roots	
	-amount of fine roots decreases on shallow and stony soils	
	-in deep loamy soils tap roots will grow to 90 % of final depth in 9 to 11 years	
	-tap roots stop growing when they encounter a root restricting layer	
	-tap roots will stop growing and branch as soon as they reach bedrock on a shallow soil site; lack of fine roots	
b.Black spruce		
	-lateral sinkers and fine fibrous feeders (multiple)	-bulk of roots confined to upper 15 cm of soil
	-maximum depth of 15 cm for laterals and fine roots	-avg. of 0.7 m by year 9
	-fine fibrous roots growing upward into L-horizon and living feathermoss	-maximum distribution of 12.3m
	-up to 18,000 kg/ha of fine roots	
	-elongated taproot on well-drained, uniform soils	
	-restricted taproot on perched water tables, compacted horizons and stratified soil	
	-mono-layered rooting on peaty-phase mineral soil with imperfect to poor drainage	
	-multi-layered rooting on peaty-phase mineral soil and thick LFH horizons	

Immediate root extension follows germination and frost heaving is seldom a problem in jack pine seeding. Jack pine germinants will not survive periodic flooding and seeding of deeply-scalped micro-sites should be avoided. Jack pine possesses indeterminate shoot growth and will exhibit rapid juvenile height growth in the absence of non-crop vegetation or drought.

Fine rooting is important because it is the fine roots which absorb and translocate most of the water and nutrients. Excessive drought or physical exposure will result in a major loss of the fine root biomass. Competition by non-crop vegetation results in a reduction of fine root biomass impacting the vigour and growth potential of the seedling.

In contrast, black spruce cannot survive and germinate when the seed is buried. Germination of the seed requires contact with the mineral soil and full sunlight. Most seed which comes in contact with mineral soil will germinate within one year. Haircap, hummock-forming Sphagnum and broom mosses provide ideal seedbeds on dry to fresh mineral soils. Shading is acceptable providing it does not drop below 21 percent of full sunlight. Black spruce, after it has become established, is more drought tolerant than jack pine with respect to stomatal conductance (we don't know about root tolerance). In addition, black spruce is capable of surviving periodic flooding. Black spruce exhibits determinate shoot growth and is easily impacted by non-crop vegetation on the site.

Conclusions

Knowledge of site-specific micro-site conditions which optimize the establishment and early growth of jack pine and black spruce is incomplete due to the lack of formal trials and measurements. Survival and growth of seeded or planted seedlings can be enhanced if field staff involved in the regeneration program rely on their past experience coupled with a solid understanding of the species' ecology and growth habits. Adaptive

Table 3. Micro-site requirements for jack pine and black spruce.

	SEEDLING ESTABLISHMENT								
Species	Light intensity	Shading	Air temp.	Mineral soil exposure	Forest humus	Soil moisture	Soil temp.	Soil texture	Competing vegetation
jack pine (seeded)	full <4 hr day	35% shade required min. 60% full sunlight	> 17°C < 47°C	25% exposure Ae with firm base	1.5 cm organic/ mineral mix	dry to moist	minimum 6°C in upper 15 cm	deep - all textures	intolerant
jack pine (planted)	same	same	same	not applicable	3.0 cm LFH over mineral	same	same	deep - all textures	intolerant
black spruce (seeded)	full maximum biomass production	required min. 100% full sunlight for height and production	> 15°C < 40°C	25% - 40% Ae (h) with firm base	nil (H mixing)	fresh to moist	minimum 6°C in upper 15 cm	coarse loamy fine loamy soils	tolerant shrubs & grasses & problem to rooting immediately
black spruce (planted)	same	same	same	not applicable		same	same	same	same
white spruce	full	requires min. 45% full sunlight for max. height growth	> 18°C < 45°C	not applicable	F & H horizons	need seasonal supply well-aerated moisture fresh to very moist	minimum 6°C in upper 15 cm	coarse loamy fine loamy silty clays	intolerant-often needs nurse crop for protection from frost. grass and sod harmful to long-term rooting.

management will only succeed when the importance of the species' biology is understood and respected.

Since those factors which will limit or support good survival and growth vary from site to site, forest managers need to utilize the Northwestern Ontario Forest Ecosystem Classification system as a basis for organizing current knowledge and identifying where the information gaps related to micro-site exist on their unit. Once identified, development and operational research projects focused on micro-site identification and testing can be organized.

The creation of optimal micro-sites is essential if we are to lower the cost per established, free-to-grow seedling, or perhaps more importantly, if the rotation ages of future plantations are to be lowered. The time has come to change our traditional dependence on the use of net mineral soil exposure (MSE) as a measure of evaluating site preparation success and replace it with an assessment of the number of quality micro-site planting or seeding chances per hectare.

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